REPORT RESUMES

ED 017 663 VT 002 893

NUMERICAL CONTROL OF MACHINE TOOLS; AN INSTRUCTOR'S GUIDE.
CALIFORNIA STATE DEPT. OF EDUCATION, SACRAMENTO

PUB DATE 67
EDRS PRICE MF-$0.75 HC-$7.88 195P.

DESCRIPTORS- *CURRICULUM GUIDES, *TEACHING GUIDES, *NUMERICAL CONTROL, TRADE AND INDUSTRIAL EDUCATION, MACHINISTS, *MACHINE TOOLS, TECHNICAL EDUCATION, JUNIOR COLLEGES, INSTRUCTIONAL MATERIALS,

IN A SUMMER WORKSHOP, JUNIOR COLLEGE INSTRUCTORS AND INDUSTRIAL SUPERVISORS DEVELOPED THIS GUIDE FOR TEACHER USE IN A 3-SEMESTER-HOUR COURSE AT THE JUNIOR COLLEGE LEVEL. THE COURSE OBJECTIVES ARE TO (1) UPGRADE JOURNEYMEN IN MACHINE TOOL OPERATION, MAINTENANCE, AND TOOLING, AND (2) ACQUAINT MANUFACTURING, SUPERVISORY, PLANNING, AND MAINTENANCE PERSONNEL AND ADVANCED VOCATIONAL-TECHNICAL STUDENTS WITH NUMERICAL CONTROL. COURSE UNITS ARE (1) INTRODUCTION TO NUMERICAL CONTROL, (2) NUMERICALLY CONTROLLED MACHINES, (3) CONTROL SYSTEMS, (4) TOOLING, (5) MACHINE OPERATOR'S RESPONSIBILITY, (6) FEED, SPEED, AND HORSEPOWER, (7) COORDINATE DEFINITION OF PART GEOMETRY, (8) NUMBER SYSTEMS, (9) PART PROGRAMING, (10) MANUSCRIPT PREPARATION, (11) ADAPT AND THE COMPUTER, AND (12) SUMMARY. EACH UNIT GIVES OBJECTIVES, SUGGESTIONS FOR INTRODUCING AND PRESENTING THE UNIT, A RESOURCE UNIT, AUDIOVISUAL AIDS, INSTRUCTIONAL AIDS, REFERENCES, AND STUDENT ACTIVITIES. SUPPLEMENTARY MATERIALS INCLUDE (1) 47 CLASS HANDOUTS, (2) A REPORT OF A SURVEY OF TRAINING NEEDS IN THE AREA OF NUMERICAL CONTROL, (3) A SAMPLE TEST, (4) A STANDARD ANSWER SHEET, (5) A FINAL EXAMINATION, AND (6) A GLOSSARY OF TERMS. MANY PHOTOGRAPHS, LINE DRAWINGS, AND ILLUSTRATIONS ARE INCLUDED. (EM)

ED017663

NUMERICAL CONTROL OF MACHINE TOOLS

CALIFORNIA STATE DEPARTMENT OF EDUCATION
MAX RAFFERTY - Superintendent of Public Instruction
SACRAMENTO 1967

VT00893

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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NUMERICAL CONTROL OF MACHINE TOOLS

N/C

An Instructor's Guide

PREPARED UNDER THE DIRECTION OF
THE BUREAU OF INDUSTRIAL EDUCATION

MEMORANDUM

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DATE: March 20, 1968

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State Dept. of Education, Editors: David Allen, James Herman & William Stanton

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Development Group Work Experience Workshop
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(3) Utilization of Material:
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Foreword

A work force that has the knowledge and skills required by industry is essential to our economy. The public schools must, therefore, offer vocational education programs that are geared to meet the needs of industry.

Vocational programs that are thus geared will be subject to constant change, for industry is now changing its methods of operation much faster than it has during any other period in our history. In making these changes, industry is continuing the use of certain available skills, eliminating the use of others, and creating need for new skills. These changes in requirements of industry must be paralleled by changes in the vocational education programs.

Industry must have the work force it requires to operate efficiently and at the level required to meet the demands of our society. The public schools must provide the vocational education programs required to produce this work force, for a well-balanced economy depends in large part on both industry and education doing their jobs well. This publication contains information that should help the schools do their jobs; its use should result in existing programs being improved and new programs being introduced where they are needed.

Max Rafferty

Superintendent of Public Instruction

Preface

The dynamic growth of numerical control of machine tools as a technique of manufacturing has made it essential to develop up-to-date instructional guidelines. An extremely limited number of credentialed instructors have firsthand knowledge of the requirements and processes of numerical control; and, until recently, each attempt to define instruction needs has been thwarted. This instructor's guide has been prepared to minimize waste resulting from false starts and from misconceptions of the scope and needs of numerical control. This is one of two volumes on the subject of numerical control to be developed by the workshop team organized in the summer of 1964.

This guide is designed to support instruction in the junior college technical programs in California. It is a part of the "Series for Technical Education Curriculum Development," under preparation by the State Department of Education. The preparation of the guide has been under the direction of Robert L. Illinik, Compton College, and Paul Henry, Cerritos College. The manuscript was prepared by a team composed of the following junior college instructors and industrial supervisors:

Dale V. Bennitt, U.S. Electrical Motors Corp.
George H. Bratt, Citrus College
T. Bruce Clarke, Mt. San Antonio College
Robin V. Crizer, San Francisco City College
Arthur S. D'Braunstein, Cerritos College
Irving E. Hicks, Riverside City College
A. Frank Klute, E. Los Angeles College
Urban J. Liewer, Long Beach City College
Charles A. Robertson, Northrop Aircraft Corp.

The workshop team spent the summer of 1964 employed in such job classifications as "Numerical Control Machine Operator," "Coordination and Shop Liaison," and "Numerical Control Programmer" in the following industrial firms:

Douglas Aircraft Corp., Long Beach Division
General Dynamics Corp., Pomona
Lockheed California Corp., Burbank
North American Aviation Corp., Anaheim
Northrop Aircraft Corp., Hawthorne
U.S. Electrical Motors Corp., Anaheim

Technical sessions, held every other Saturday throughout the summer, provided opportunity for participation by many resource persons from local industry. William B. Johnson of Rocketdyne Division, North American Aviation Corp., worked tirelessly to provide information about the latest numerical control practices. Many local members of the American Society of Tool and Manufacturing Engineers (ASTME) served in advisory and resource capacities, contributing in many ways to the development of this guide.

Resource materials, illustrations, and background assistance used in preparation of this manuscript were provided by the following persons:

Robert A. Cole, Tornquist Machinery Co.
Kenneth Dunlop, Machinery Sales Corp.
Joseph E. Furtner, Rheem Electronics Corp.
Robert Godfrey, United Machine Tool Co.
Ernest F. Hennis, ExCello Corp.
Harry Isaman, Bendix Corp.
Larry Ivins, Rheem Electronics Corp.
William Judd, Pratt & Whitney Co.
George Kinney, Hughes Industrial Systems
Walter Kinney, Douglas Aircraft Corp.
Bruce Lockway, Hoffman and Heart
William Mathies, North American Aviation Corp.
Tom McEachern, Germain-Moore Machinery Co.
Douglas Morrison, Dayton and Bakewell
Roy Nelson, Bendix Corp.
Brad Peck, General Electric Co.
Jerry Quales, Service Bureau Corp.
Aubrey G. Roberts, Ellison Machinery Corp.
Warren Seacrest, North American Aviation Corp.
David Simpson, Burgmaster Corp.
Larry Utterback, North American Aviation Corp.

To provide assistance to instructors in the development of instructional materials, this guide includes handout materials, so marked, for local duplication. The handout materials may also be converted to transparencies for projection. Guidance is offered to ensure adequate student participation and drill in the absence of clear choices in available textbooks.

Special acknowledgement is extended to David Allen, University of California at Los Angeles, to James Herman, and to William Stanton for their assistance in coordinating the arrangements for the nine weeks of the workshop and for the months of rewriting involved in the total effort.

DONALD E. KITCH
Acting Chief,
Division of Instruction

RICHARD S. NELSON
Chief, Bureau of
Industrial Education

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Course Description

Catalog Description

18 weeks 3 hours per week

Numerical Control of Machine Tools (N/C) is an introductory course offered to acquaint the student with theoretical principles and practical applications of numerical control as applied to machine tools and related instruments. The relationships between mathematics and machining principles are presented, along with guidelines for further study in the field.

Required Background or Prerequisites

Familiarity with manufacturing techniques as accomplished with conventional machine tools is required. Competence in machine tool operation and setup, in some phase of machine tool maintenance, in manufacturing planning, or in tooling coordination is essential.

Course Objectives

To provide to journeymen an opportunity to upgrade skills in machine tool operation, maintenance, or tooling

To acquaint manufacturing supervisory, planning, and maintenance personnel with the state-of-the-art in numerical control

To acquaint advanced vocational--technical students with current developments and trends in numerical control

Methods of Instruction

Lectures

Chalkboard illustrations

Audio-visual aids

Problem solving

Home study assignments

Equipment and materials demonstrations

Evaluation

Error analysis

Methods of Evaluation

Examinations

Class discussions

Home study assignments

Class exercise assignments

Notes

Continuous followup by instructors involved in the program is made mandatory by current rates of development of equipment, methods, and applications.

Local advisory committees should include representatives from the membership of American Society of Tool and Manufacturing Engineers (ASTME) and, wherever possible, representatives of firms associated with Aerospace Industries Association (AIA).

Sufficient standardization has been achieved to render feasible the preparation of training aids and the procurement of basic units of equipment for demonstration and student tryout, using prepared materials and control media. Instructors should be encouraged to use available card and tape preparation equipment and to perform exercises in a professionally useful manner, including tryout of the prepared control media on suitable N/C equipment and computers.

unit 1
INTRODUCTION TO NUMERICAL CONTROL

PLAN OF INSTRUCTION

Objectives

- To introduce the student to the meaning of numerical control (N/C) and to its application to the control of machines and of manufacturing operations and processes
- To introduce the student to occupational opportunities in the field of numerical control
- To acquaint the student with advantages and disadvantages of numerical control and with the economic factors involved

Introduction

1. Define course objectives and limits of course coverage.
2. Discuss the historical background of tool development and automation.

Presentation

1. Define numerical control.
2. Discuss the history of N/C.
3. Establish the advantages and disadvantages of N/C.
4. Present economic justification for N/C.
5. Describe background, education, and training requirements for N/C personnel.
6. Discuss career opportunities.

RESOURCE UNIT

Definitions

The Electronics Industry Association (EIA) in their Automation Bulletin No. 3A, July 1961, states that numerical control is "a system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of these data."

The treatment in this guide will include an understanding that the principle of feedback is also involved; i. e., that there is a continuous evaluation of the data and of the resultant movement or action.

The term "conventional" is applied throughout this book to machines that are man-operated and man-controlled, shops so equipped, and to the related items.

The glossary in the appendix will prove helpful in defining many terms associated with N/C.

Historical Background

The concept of N/C is not new. It is frequently assumed that this field is a branch of electronics, but in fact other power and signal techniques are commonly used. Familiar items such as the music box and the player piano utilize some of the same principles which made possible the development of complex systems of numerical control.

In 1725, M. Falcon invented a system that would operate a loom by means of punched cards. The cards controlled the mechanical linkage that caused needles to pull specified colors of thread through cloth at specified locations. In 1807, Joseph Jacquard produced an improved card-controlled knitting machine, permitting greater production; his method is still widely used. Many examples of the use of transfer mechanisms and automatic processing can be found in the annals of U. S. industrial development. It has been reported that an automatic grain mill, built on or near George Washington's farm at Mt. Vernon, used water power and was capable of processing grain continuously without the presence of an attendant.

More compact and effective control systems were developed, and the availability of industrial power improved. Increased attention was given to the efficiency of production equipment and processes, to the handling of material, and to the development of automatic processes. In 1912, Scheyer applied for a patent for a cloth-cutting machine that provided a means for controlling angular motion in any direction in space, either in one plane or several, by means of a previously prepared record, such as a perforated sheet of paper or other material.

In 1949, the Air Material Command (AMC), U. S. Air Force, let a development contract to the Parsons Corp., with the objective of improving the processing of templates by means of mathematical development of cutting tool locations, using computer programs. Although little hardware was developed under this contract, much knowledge was gained with respect to the predetermination of cutter paths, the coordinate locations of points and series of points, and the feasibility of devising computer programs for their determination. The Air Force interest in the potential for tooling development resulted in an awareness that much greater potentials for machine control existed.

To evaluate these potentials and apply them to the development of actual hardware, the AMC let a contract to the Servo-Mechanisms Laboratory of the Massachusetts Institute of Technology (MIT) early in 1951. As a result, one year later a three-axis numerically controlled Cincinnati machine tool was demonstrated to the Air Force (Fig. 1-1). When the machine was demonstrated in 1952 to the major airframe manufacturers to acquaint them with the concept of N/C, the tremendous interest aroused by the demonstration led to the immediate initiation of further studies and proposals.

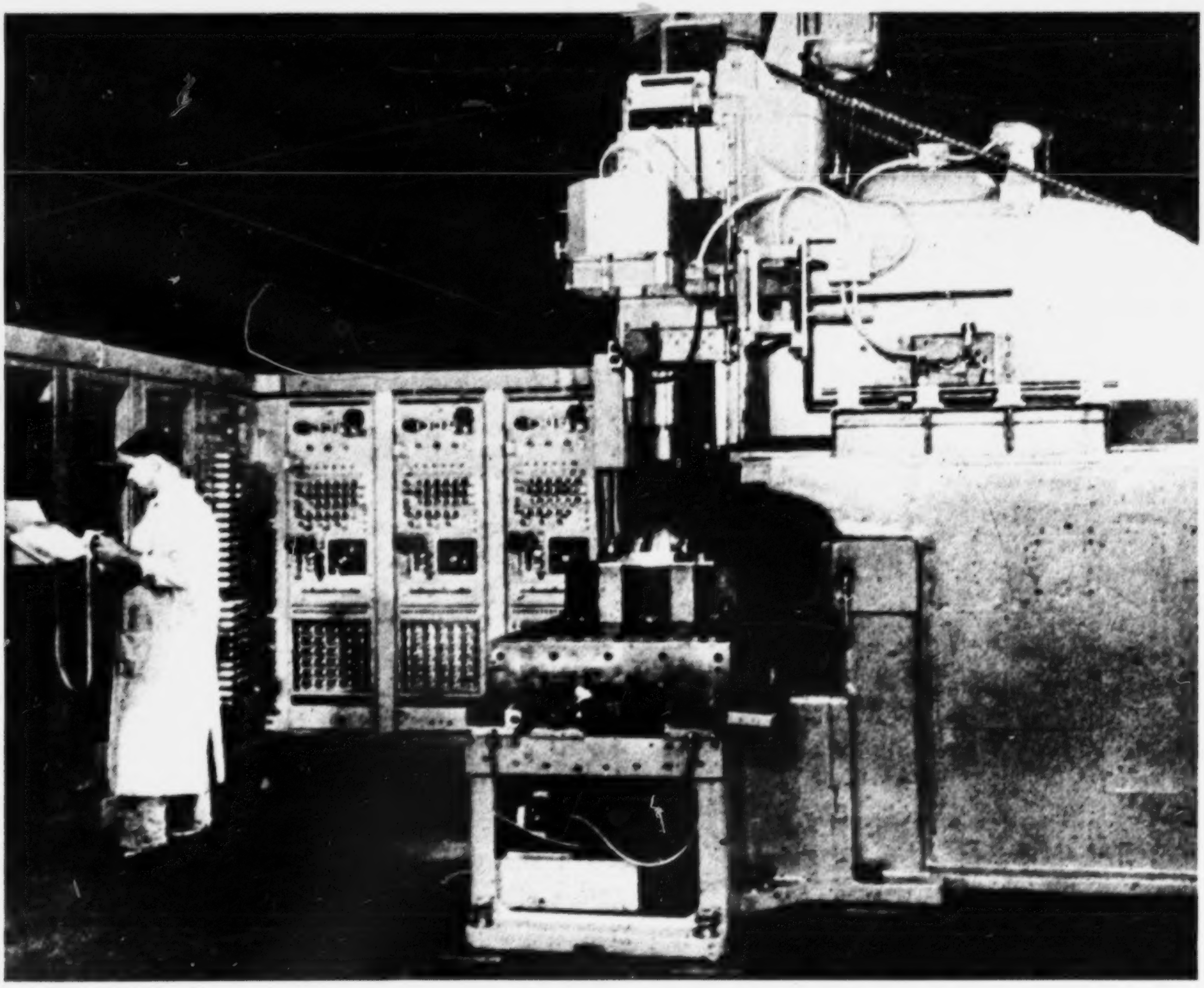

Fig. 1—1. The original numerically controlled machine tool—a retrofit from a standard Cincinnati Hydro-Tel mill

The first activities of the Parsons Corp. had concentrated on the determination of specific points in space. The effort at MIT revolved around the more sophisticated problem of the continuous control of a machining path. As the machine tool, airframe, and aerospace industries began to evaluate the potentials of N/C, interest was renewed in the earlier point-to-point procedures.

Meanwhile the Aerospace Industries Association (AIA) established a subcommittee for N/C, and in cooperation with the EIA initiated the formulation and publication of standards to assist in guiding the burgeoning developments in the N/C field. In 1955 the Air Force authorized large purchases of N/C machine tools, and this action is generally credited with giving major impetus to the machine tool industry to go all out in tool and control system development.

In 1952, personnel at MIT had become aware of tremendous problems in providing the computations necessary to program complex parts. Computers made the calculations very rapidly, but the time required to prepare the programs for the computers was excessive. Research was begun to devise means to permit maximum utilization of N/C. In March, 1956, Arnold Siegel reported the development of a system of automatic programs for two-dimensional machine tool control using MIT's Whirlwind I computer. Siegel's system was further examined, and by the end of the year had developed into an English-like language that permitted rapid, adequate, and repetitive communication with specific computers. It was given the name APT, an acronym for Automatic Programmed Tool (language). Research and development on this project continued at MIT until May, 1958, when the Institute resigned as coordinator of the project.

The AIA then assumed the coordination role, producing an improved and expanded version called APT II. In January, 1962, the Armour Research Foundation took over the project for long-range development. The Illinois Institute of Technology Research Institute (IITRI) developed APT III for use on the advanced IBM 7094 computer.

Until recently APT has been under proprietary control, although it had become a de facto standard in at least two major industries and had gained extensive usage in others. A new policy of the APT Administrative Board will permit the inclusion of APT in N/C courses and curricula. And there is growing prospect of the adoption of APT as both an American and an international standard.

An abridged version of APT, called ADAPT, has been developed for use on smaller computers, such as Univac 890, IBM 1620, and IBM 360. ADAPT, first published in 1964, is compatible upward with APT; a brief instruction period can make a programmer who has learned the shorter version proficient in APT. Because the smaller computers are becoming increasingly available on junior college campuses, ADAPT material is included in this guide, and ADAPT is deemed quite satisfactory as a teaching tool for the immediate future.

Economic Aspects

Tooling improvements have generally proven rather easy to justify from the economic standpoint, and numerical control, as a new and remarkably efficient tool, is no exception. Nevertheless, N/C offers many advantages that considerably outweigh several rather serious disadvantages. Consideration of both advantages and disadvantages, however, is necessary to a good understanding of the N/C concept and its impact upon industry.

Some of the important advantages are that N/C:

- Makes possible machining of many once "unmachinable" parts
- Reduces lead time
- Improves both accuracy and repeatability
- Makes accurate machining time estimates possible
- Minimizes the potential for human error
- Results in reduction of operator fatigue
- Permits design changes more easily (and economically)
- Has potential for more efficient tool planning
- Improves the efficiency of small-lot production
- Permits holding to closer tolerances
- Greatly reduces nonproductive machine time

The disadvantages of N/C most often noted include:

- Higher initial cost of numerically controlled machines
- Extensive additional training required for operators to ensure optimum machine utilization
- Production methods not usually the best for large quantities or long runs
- Accelerated technical obsolescence due to rapid changes in the state-of-the-art
- Requirement for additional peripheral equipment
- Requirement for full utilization of capabilities and competent understanding of limitations to make N/C equipment economically profitable
- Requirements for special provisions for cutting tools, special setup equipment, and thorough planning

In spite of these serious disadvantages, numerical control cannot just be ignored. More and more government contracts specify that a percentage of the machining must be done through the use of N/C. It is predicted that N/C will be applied to more than 90 percent of all aircraft fabrication operations. Applications are being developed for processes as varied as welding, typesetting, circuit testing, communications routing, and electronic component assembly. The development and production of more compact computers and of more versatile control systems can only increase the utilization of numerical control.

Personnel Development

The major changes in personnel requirements brought about by N/C point in a single direction--toward more training. Technical training in the schools has the inside track for the first time; it is now possible, through adequate training, to leapfrog many intermediate jobs and go directly to the better-paying technician positions. The required training can be obtained either in upgrading or in preemployment programs.

Several new job categories have come into being as a result of N/C requirements. The most notable new category is that of N/C parts programmer, for which there is an increasing demand. At least two studies have been made to determine the requirements of this new job: one was made locally in the plants that participated in the workshop program on which this guide is based; the other was a national study by an industrial concern. The results of both studies indicated that the primary requirement is a thorough knowledge and understanding of machining principles and techniques. In addition, competence in mathematics, including analytic geometry, and proficiency in drafting, including descriptive geometry and basic tool design, are important.

Early attempts to produce N/C machine operators and programmers were made from some false premises. An increasing number of plants are realizing that, except for the simplest point-to-point installations, the untrained operator cannot be used effectively and economically. Study after study has shown that machinists with the highest skill in conventional operations are the ones that can be developed into the ablest, most productive N/C machine operators for multi-axis and machining center installations.

Similarly, the first programmers were recruited from the ranks of mathematicians and engineers, but it was quickly found necessary to support them with competent all-around machinists or toolmakers. In most instances it proved easier for the practically-oriented shop man to grasp the necessary mathematics than for the talented mathematician to gain "machining sense." From the experience of the pioneers in numerical control has come the conviction that in the realm of N/C the man with a solid grounding in shop practice is the potential king.

It has been suggested that while the number of expert programmers must increase, the number of skilled machinists required must decrease. Training programs can help immeasurably to lessen the shock resulting from increased automation (of which N/C is a substantial part) by interrelating and coordinating the traditional mathematics, science, and communications subjects with the industrial applications that require more and more utilization of those subjects. Training programs that take such a direction will make possible the effective upgrading of journeyman machinists and toolmakers, and will provide more appropriate training to youth in preemployment programs.

INSTRUCTIONAL TECHNIQUES

References

Begeman, M. L., and B. H. Amstead. Manufacturing Processes (Fifth edition). New York: John Wiley & Sons, 1963.
Numerical Control in Manufacturing. Edited by F. W. Wilson. New York: McGraw-Hill Book Co., 1963.
"Train Students Early for N/C". The Iron Age (January 24, 1963).
Miscellaneous reprints from American Machinist.
Miscellaneous reprints from Tooling and Production.

Handout Materials

Brief History of Numerical Control (Handout Sheet No. 1-1)

Audio-Visual Materials

The Evolution in Manufacturing Control. Technical Education Set #100. 45 slides. Distributed by E & F Photo Specialties, 2120 W. Beverly Blvd., Montebello, Calif. 90640. Script distributed by California Numerical Control Workshop, P. O. Box 75, Westminster, Calif. 92683.
Manufacturing by Numerical Control. Color film, 27 min. Available on loan from Bendix Corporation, Industrial Controls Division, 8880 Hubbell, Detroit, Mich. 48228.

Instructor Activities

Obtain samples of parts, tape, control manuscripts, and other communication or output materials.
Present cost comparisons for actual production samples.
Contact machine tool and control system distributors for examples and material samples.
Outline a resumé pattern for student use.

Student Activities

Prepare a resumé for use later in the semester in planning additional training needs. Include background, education, machining training and experience, drafting and tool design ability, maintenance, planning, and other experience.

Handout Sheet No. 1-1

BRIEF HISTORY OF NUMERICAL CONTROL

Date	Event
Many years ago	Music box and player piano; no feedback was developed.
1725	M. Falcon of France used a deck of punched cards to control a loom; no feedback capability was developed.
1936	Building-block automation introduced into Detroit auto industry; groundwork was laid for feedback capability.
1941-45	Advancement of firecontrol devices by U. S. and British navies; feedback capability was developed.
July, 1949	Air Materials Command let contract to Parsons Corp. to develop numerical control for machine tools. Basic knowledge, but no hardware, resulted.
Early 1951	New contract was let to MIT.
March, 1952	MIT outfitted a Cincinnati Hydrotel, and parts were cut.
October, 1952	MIT demonstrated N/C to U. S. Air Force, who undertook study.
January, 1954	Air Force requested major airframe manufacturers to submit proposals for machine tool control to reduce production costs by N/C. Proposals were received, but no contracts were let.
June, 1955	Aircraft Industries Association set up a committee for the study of N/C.
Late 1955	Air Force authorized bulk purchase of N/C equipment.
March, 1956	MIT unveiled automatic program for use with MIT Whirlwind Computer, two dimensional only.
December, 1956	APT (Automatic Programmed Tool), English-like language, introduced.

May, 1958	Armour Research Foundation succeeded MIT as program coordinator; proceeded on development of APT III.
Summer 1964	ADAPT introduced (non-proprietory small-computer version of APT).

unit 2

NUMERICALLY CONTROLLED MACHINES

PLAN OF INSTRUCTION

Objectives

- To acquaint the student with the various types of numerically controlled machines
- To familiarize the student with the potentials and limitations of N/C in manufacturing processes, compared with conventional methods

Introduction

1. Define a machine tool in terms of its functions.
2. Discuss conventional methods of control: manual, cams, tracings, record-playback, variable program, and automatic processing.

Presentation

1. Illustrate the capabilities of various machine tools which have been adapted to N/C.
2. Discuss the various machine tool classifications in industry.
3. Discuss retrofitting of conventional tools.
4. Elaborate on the machine tool configuration changes that result from elimination of the necessity to coordinate the physical dimensions of the machine with the characteristics of human operators.
5. Discuss machine tool accuracy potentials, and examine factors in construction, installation, and maintenance of N/C machine tools.

RESOURCE UNIT

Machine tools can be described as power-driven metalworking tools that produce finished work by removing chips of metal. Such tools can be grouped into five families: drilling, turning and boring, planing and shaping, milling, and grinding. There is little overlap between groups, and separate machines of the conventional kind have been required to perform each class of work. All too frequently these operations have been routinely specialized with respect to labor skills and equipment. Emphasis upon improvement of productivity has resulted in the development of automatic work cycles coupled with interrelating of specialized capabilities. This has led to building-block or "Detroit-type" automation which is suitable for large quantity production of identical items.

Improvements in the ability to control both accuracy and production time were essential to facilitate the tooling and prototype functions of the productive cycle. Productivity rose as strictly manual control gave way to the use of automatic cycles and control camming. Tool designers and methods engineers strove to incorporate operator skill into the machine and into operational tooling. Tracing controls provided more flexibility and better control of accuracy, leading to reduced tooling outlay. The greatest flexibility of automatic control was achieved when record-playback and dial-in capabilities were incorporated into automatic equipment.

N/C Machine Tool Capabilities

The development of more and more automatic controls did not continue to give proportionate returns so long as human control was relied upon to maintain variable relationships. Numerical control studies suggested two ways to increase these returns--by improving accuracy and reliability and by reducing setup time and other downtime to previously unheard-of levels.

It takes one-twentieth as long to produce a complex part to a tolerance of 0.0005 inch by numerical control as it does by manual control. It has long been axiomatic that the greater the number of parts to be manufactured, the higher the potential quality and the lower the cost per part. With N/C the quality and cost advantages of volume production can be applied to short runs, while the flexibility of general-purpose machine tools is still maintained.

Benefits also accrue from the use of N/C to turn out large quantities of repetitive products, when compared to conventional methods. The numerical control unit, which often costs twice as much as the machine tool itself, pays off in tremendously increased productivity. Compare, for example, a conventional tracer-type profile-milling machine and an identical machine with N/C instead of tracer control. With the N/C machine, lead time is reduced by 92 percent and machine operation running time by 84 percent. Essential tooling for the two machines compared is drastically reduced in the case of the N/C machine.

Since no pattern is required, all of the cost normally involved in the production, storage, and maintenance of a pattern is eliminated. A small roll of tape stores all of the information necessary to guide the cutting tool through the required cutting path. The resultant part is more accurate than one made with a tracing pattern, both dimensionally and in surface finish. (See Fig. 2-1.) At any later date, an exact duplicate can be reproduced without the warping or disfiguration often noted in parts produced from a tracing pattern.

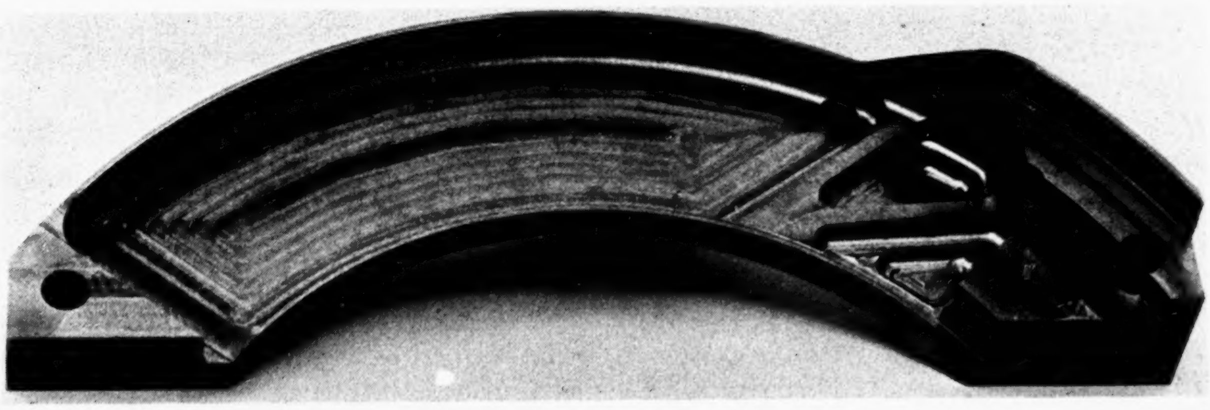

Fig. 2—1. A contour-milled aircraft component at the completion of the N/C operation

Another significant factor is the ability of N/C equipment to produce exact mirror images or inverted shapes and contours by merely changing the position of an axis inverter switch. Punches and dies, or both members of a forming die, can be produced at a minimum of tooling expense and with extreme accuracy. N/C also permits production of right- and left-hand parts that are exact pairs, an especially important consideration in aircraft, aerospace, and naval fabrication.

Once the program for a specific part is on tape, no further concern is required. Stockpiling finished parts to maintain economical job lots is unnecessary. Time studies indicate that even a single part is often cheaper to produce by N/C than by any conventional technique, when costs of programming, setup, and running times are included, particularly if the part is highly complex. For subsequent productions of a part, costs can be closely estimated and contract bidding results thereby made more predictable. Numerical control gives a definite competitive advantage to the company that makes fullest use of it.

Industrial Applications

The accelerating growth of N/C has provided a dramatic stimulus to manufacturing in general and to machining in particular. Increases in productivity in areas where N/C has been adopted have been as high as 15 or 20 to 1. Even more dramatic have been the improvements in quality control. Scrap has been greatly reduced. However, when industry finds itself capable of reproducing formerly unheard-of configurations in unbelievably low machine times, the question of quality must be seriously examined. In practice, parts have been so nearly identical and so precisely what the designer specified that 100 percent inspection, using conventional techniques, has proved more costly than the machining operation.

To handle this problem, more and more N/C quality test equipment is being developed. This equipment operates in substantially the same way as the machining equipment, often using the same tape. One proposed unit has a four-axis capability: three linear axes mutually perpendicular and one rotary axis. (See Fig. 2-2.) Dial test indicators, having delicate readout and often using air-gaging or electronic sensing techniques, enable comparisons of 50 millionths of an inch or less. Once a part has been inspected, manufacturing on the N/C machine can proceed with a high repeatability factor.

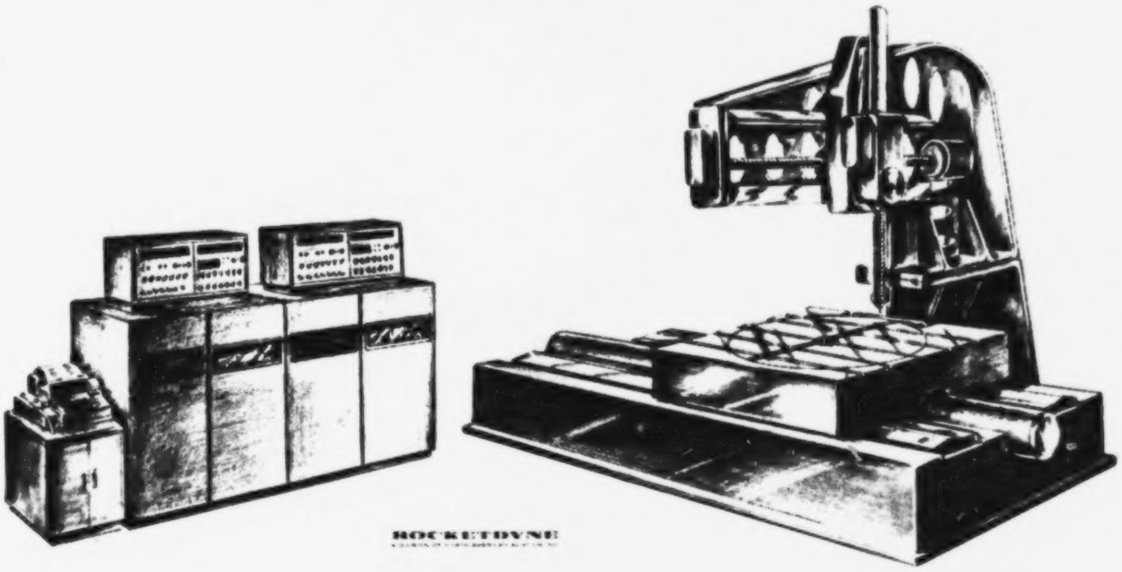

Fig. 2—2. Artist's conception of a numerically controlled inspection machine

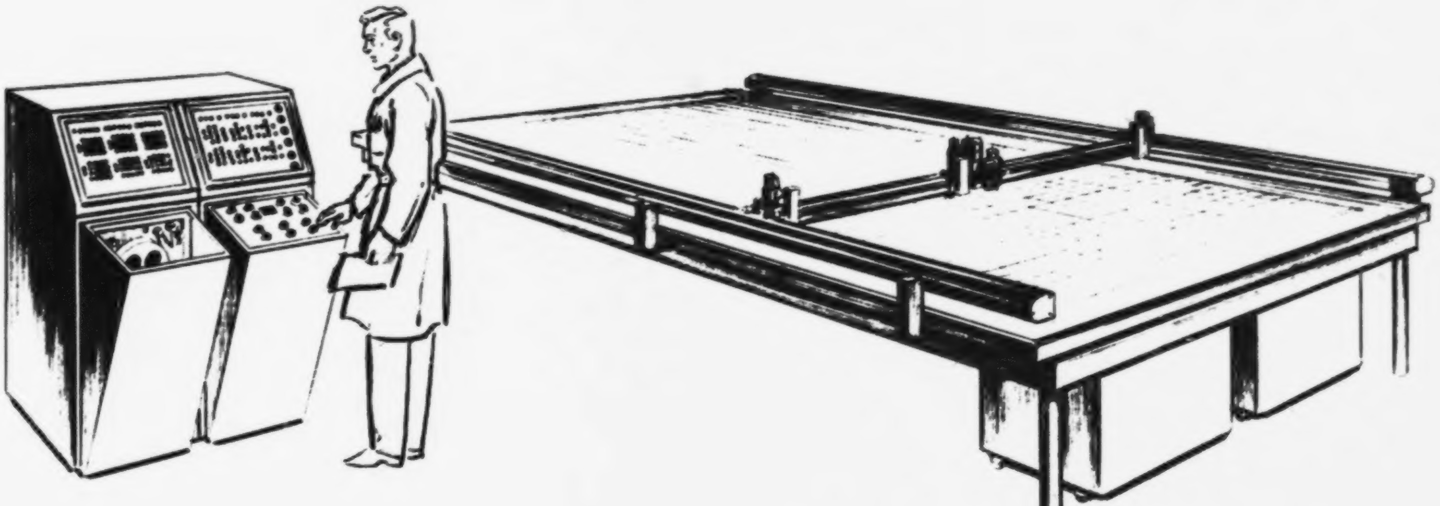

Fig. 2—3. Artist's conception of an N/C drafting machine

Although 60 percent of all machine tools sold through June, 1962, went to six industries (aircraft, metalworking, general industrial machinery, motor vehicles, special industrial machinery, and ordnance), other industries are discovering economic advantages. Applications are being found in drafting (Fig. 2-3), tube bending, welding, plating, tool and cutter grinding (Fig. 2-4), electrical-discharge machining, and many others. As new applications prove to have economic advantage, N/C equipment will be used to some extent in every industry, and by 1975 a fourfold increase in the number of N/C tools in use is forecast.

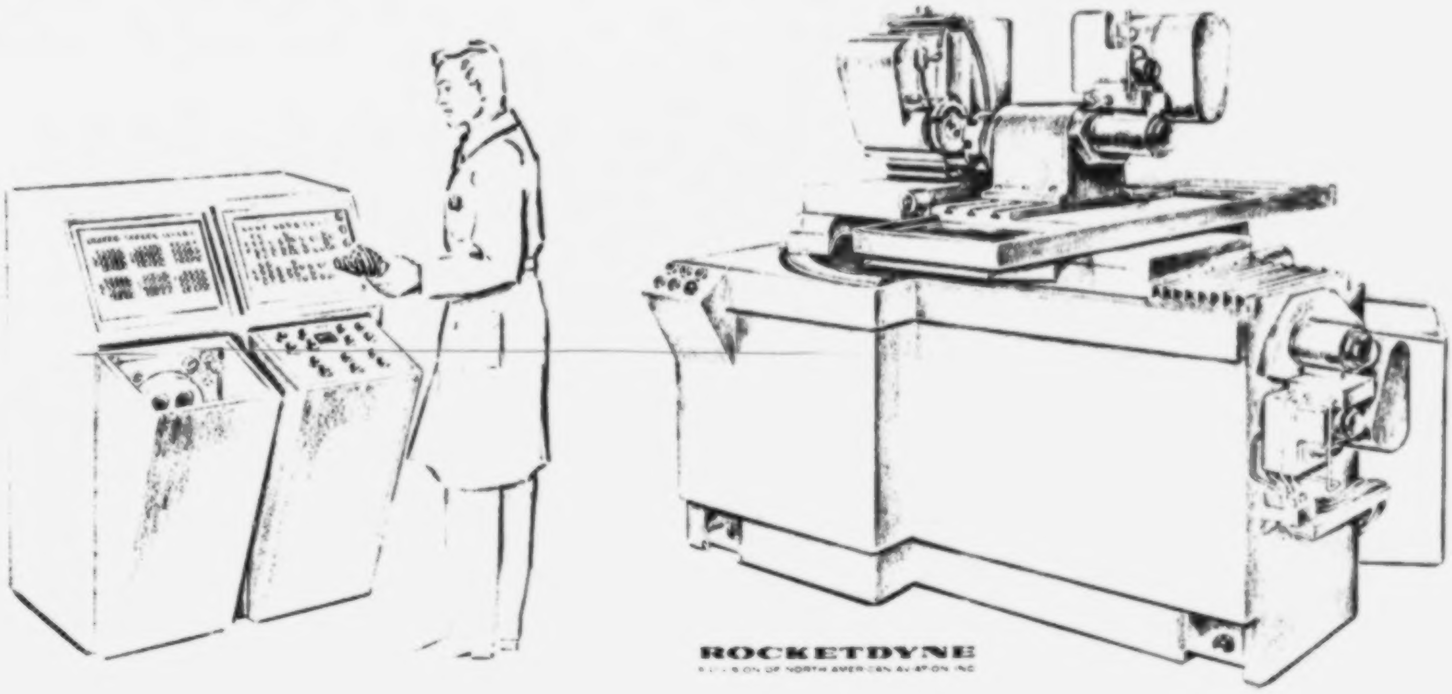

Fig. 2—4. Artist's conception of an N/C tool and cutter grinder

Equipment Availability

The very nature of the N/C concept is stimulating to those adopting the technique. For the first time the designer has full control of the product from drawing through final inspection. To the dramatic reduction in lead time must be added the ability to make major dimensional changes, without serious delay or cost penalty, up until the moment machining actually starts. Tape changes can be made with only minor expense, while the tooling , because of its simple nature, may require no engineering change that results in charges. Processes have been developed that reduce machine run time by 65 percent and more. Airframe structures with complex drafts, contours, and mold lines can be machined with ease after a greatly shortened lead time. (See Fig. 2-5.)

Machine tool builders, realizing the increasing competitive advantages, are devoting more of their capacity to the development and production of machines equipped with numerical control. Even so, supply will not soon catch up with demand. Therefore, attention is again on refitting conventional equipment with N/C. This is a relatively simple problem on some machines, such as the

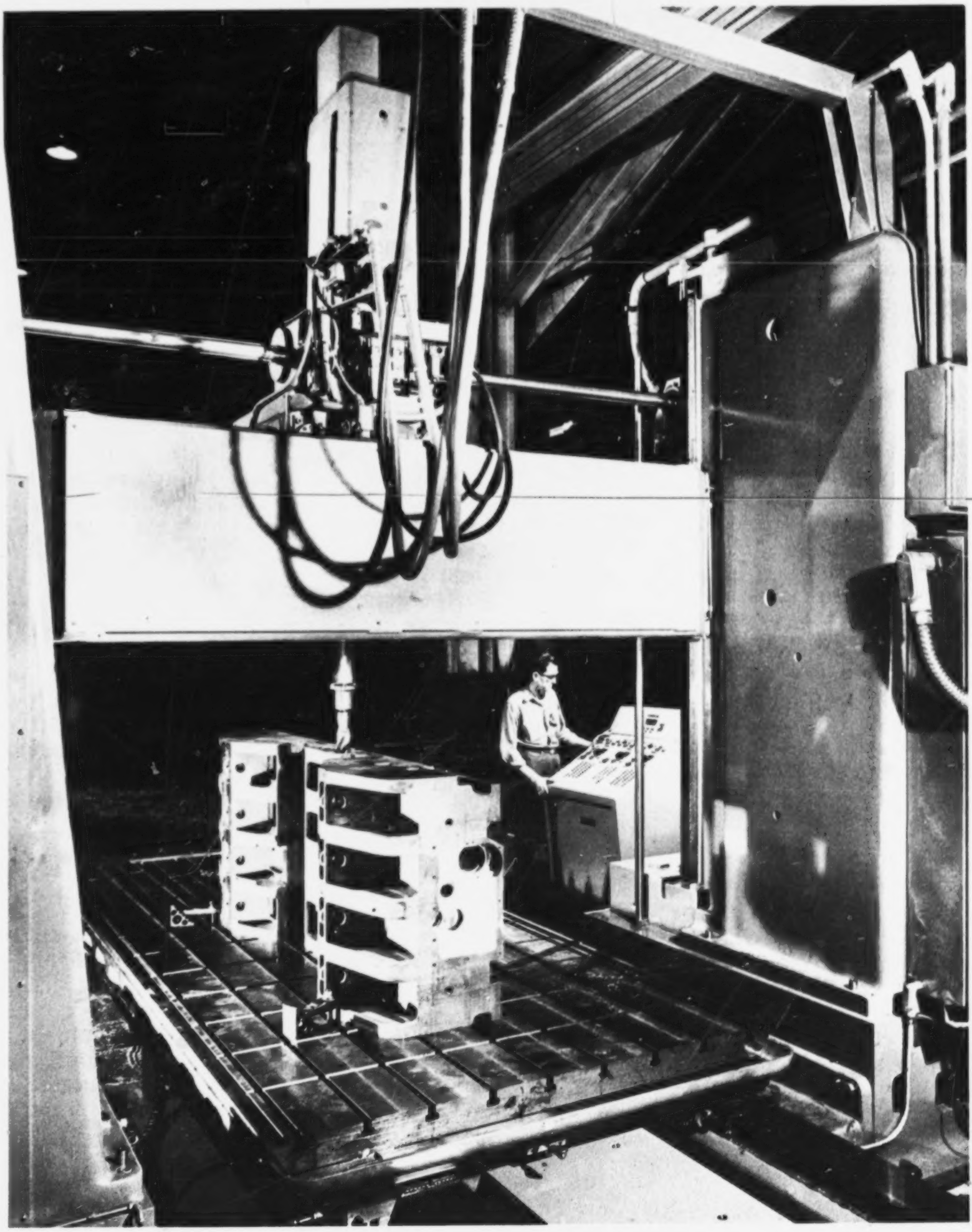

Fig. 2—5. A numerically controlled rail-type machine tool with remote operator control console

Hydro-Tel by Cincinnati. Indeed, the first N/C machine produced at MIT was just such a retrofit (Fig. 1-1). As pressure increases on heavily backlogged machine tool builders, retrofit will be increasingly considered. Improved controls and power sources have widened the applicability of retrofit techniques; lower cost of surplus conventional machines will improve the economic feasibility of rebuilding and converting. As these problems are resolved, the result will be increased job opportunity in machine tool retrofitting. This is just one of many areas that will have a great need for trained personnel. Already a severe shortage of adequately trained maintenance technicians exists. The combinations of mechanical, electrical, hydraulic, pneumatic, and electronic devices that N/C comprises create a demand for a type of technician that has only rarely, and usually by accident, been developed. A team of specialists is needed, each teaching the others his specialty.

The Machining Center

There is a revolution, too, in the structural configurations of machine tools. In conventional tools the physical limitations of the human who controlled the machine limited its design. With N/C the efficiency and effectiveness of the machining operation become the determining factors. With human limits on design removed, a part involving all of the conventional operations can be completely machined in one continuous series of operations.

The configuration that makes this possible is called the machining center. The machining center incorporates a tool magazine and changes tools automatically in response to a program of tool use. In the more sophisticated versions, complete contouring control is made possible by continuous tool monitoring. Shuttling pallets load and unload parts, while machining continues, with virtually no setup time, on parts that may be completely different. Tooling is preset to exacting standards, enabling tool replacement with no loss of machining time or accuracy.

Machine Tool Reliability

Continuous operation capability stands out as the dominant contribution of N/C. It is coupled with repeatability, a high degree of quality assurance, and the economic advantage of applying all three to the production of small lots. Conventional tools vary in the accuracy they can maintain consistently; their quality potential is influenced by part complexity, cutter accuracy, and the amount and kind of material being removed. However, because the most difficult variable to control is the machine operator, the major improvements in machine tool design in this century have been those which would minimize the human variable.

Routine checks for wear and tear are effective to a greater degree in mechanical, electrical, hydraulic, and pneumatic systems. But potential breakdowns in electronic components are not easily spotted. The more recent electronics equipment includes self-checking features that identify malfunctions before any damage to the machine tool or the workpiece results. Reliability is increasing, and manufacturers continue serious study of the problems of identification and isolation of malfunctions and ease of service. As all reliability factors are improved, numerical control systems will last as long as the machine tools to which they are adapted.

INSTRUCTIONAL TECHNIQUES

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Numerical Control in Manufacturing. Edited by Frank W. Wilson. New York: McGraw-Hill Book Co., 1963.
Aerospace Technical Forecast 1962-1972. Washington: Aerospace Industries Association of America, Inc., 1962.
The U. S. Industrial Outlook for 1963. Washington: U. S. Department of Commerce, Business and Services Administration, 1963.
Miscellaneous reprints from American Machinist (August 8, 1960), (March 19, 1962), (June 10, 1963), (July 22, 1963), and others.
Miscellaneous reprints from Metalworking (March, 1962), (December, 1962), and others.

Handout Materials

N/C machine tool descriptive brochures, available from machine tool manufacturers and distributors. Request on school letterhead.

Audio-Visual Materials

Machine It For Less. Film produced by Cincinnati Lathe and Tool Co. Available from Tornquist Machine Co., Los Angeles.
Command Performance. 16 mm. sound color film, 30 min. U. S. Air Force Regional Command. Available on loan.

Instructor Activities

Following lecture/discussion period, hand out a prepared list of available reading materials from which questions like the following can be answered.

Student Activities

1. Illustrate axis designations for various classes of machine tools.
2. For small-lot production, compare the economic factors of N/C equipment and conventional equipment.
3. Discuss the use of N/C equipment in industry, with respect to (a) cost evaluation, (b) machinability, and (c) feasibility.
4. Explain the difference between automatic and N/C equipment.
5. How does N/C relate to automation?

6. Describe a class of work which would be virtually impossible without N/C.
7. Outline briefly the stages in the development of N/C.
8. Outline a preventive maintenance schedule for conventional equipment.

unit 3
CONTROL SYSTEMS

PLAN OF INSTRUCTION

Objectives

- To introduce the student to concepts of control and acquaint him with the functions of a control system
- To familiarize the student with the characteristics of open-loop and closed-loop systems and identify the components by which control is accomplished
- To introduce input media, feedback, and control error as they relate to machine control

Introduction

1. Review definition of numerical control (N/C).
2. Illustrate a simple control system (e. g., thermostat), explaining feedback principle; then relate the system to normal machine operation procedures.

Presentation

1. Develop the concept of open-loop and closed-loop control.
2. Describe the Basic Wheel of Control.
3. Elaborate on the functions of each unit of the Basic Wheel of Control.
4. Identify the input media, related storage concepts, and hardware.
5. Elaborate on feedback, its purpose, and how it is accomplished in the control of a tool.
6. Discuss control maintenance and the problems of malfunction.

RESOURCE UNIT

The concept of control devised by the Parsons Corp. when setting out to reduce the time and cost of operations in template manufacture is quite logical and simple. Yet it updated a tooling technique over 50 years old.

Until now in the twentieth century practically every apprentice or machinist trainee has had to produce a C clamp, or similar part, by drilling out the unwanted portion of stock and filing down the irregular surface left by drilling. The need for greater precision has prompted use of the jig borer to produce hole patterns that would determine template mold lines. To speed up calculation of table settings for drilling and boring the holes, newly developed card computing techniques have been applied. The curve specifications have been converted into coordinates for the hole centers, and the coordinates in tabulated form have been used by the operator to position the table manually.

A significant reduction in at-the-machine calculation time has been realized. From further experiments has come a concept of using the punched cards to actuate and direct machine tool movements. This in turn has necessitated development of a means of verifying the position of the work table, to replace the rods and indicators of the standard jig borer. Such a means was adapted from fire control mechanisms perfected during World War II and was described as a feedback system. Fig. 3-1 illustrates a typical unit system.

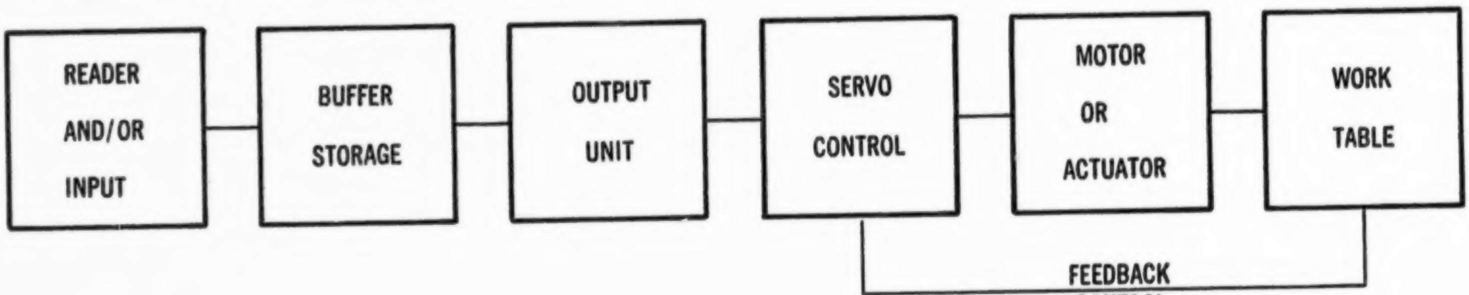


Fig. 3—1. Block diagram of control system with feedback

Coded information, in the form of punched tape or cards, is read by the reader, transferred to storage until called for, and then sent through the output unit. The output unit actuates the servo control, which generates motion signals that actuate the power source (motor). The work table moves the prescribed distance in the proper direction. Without a means of verifying the position of the table at the completion of its motion, what has just been described is no more than another automatic control sequence. But when the axes of motion are monitored and interconnected with the servo control, location signals are sent back continuously for comparison with the position signals originally transmitted.

Open-loop and Closed-loop Control

All control systems have the same basic units of control. They are adapted to the precision requirements of machine technology by the manner in which they are arranged into cycles or loops. Each loop system reacts to loads by means of appropriate sensing devices, amplifiers, and circuitry through which information about the load is transmitted to the center of control. It is at this point that a control system is identified as an open-loop or closed-loop system.

To illustrate the possible degrees of control within a system, the control of the temperature in a home can be considered. When the heater control consists simply of an off-on switch, it is an open-loop control. The human resident accomplishes all actions--switching on, feeling the temperature rise, switching off, and so on. If a small thermometer is placed where it can be used as a reference, the control system is improved through improvement of the sensing function. But since it still depends upon a manual link, it is still an open-loop system, as is the operation of a conventional machine tool by a machinist.

A thermostat can be inserted into the home heating control system in such a manner that the heat is switched on when a set low limit is reached and turned off when a set high limit is reached. This is a simple closed-loop control system. It can be made fully automatic if connected to a full air conditioning system that provides both heating and cooling action. And by insertion of a clock mechanism, the set limits can be changed for night and day variations.

Such a system can illustrate the function of numerical control as well. The system can be expanded to include a reader that will accept a control tape to regulate temperature variations according to a predetermined pattern; this tape can include changes in the high and low temperature limits as frequently as desired. The taped pattern could either cover a definite period of time or repeat itself indefinitely.

The Basic Wheel of Control

A truly flexible control system must include components which sense, amplify, transmit, receive, activate, and verify or compare. The components may be electrical, electronic, hydraulic, pneumatic, or mechanical--or any combination of these. Their relationship to each other in achieving positive, but flexible, control is continuous, and with feedback may be represented by a closed loop. The essential elements of an automated control system are shown in Fig. 3-2.

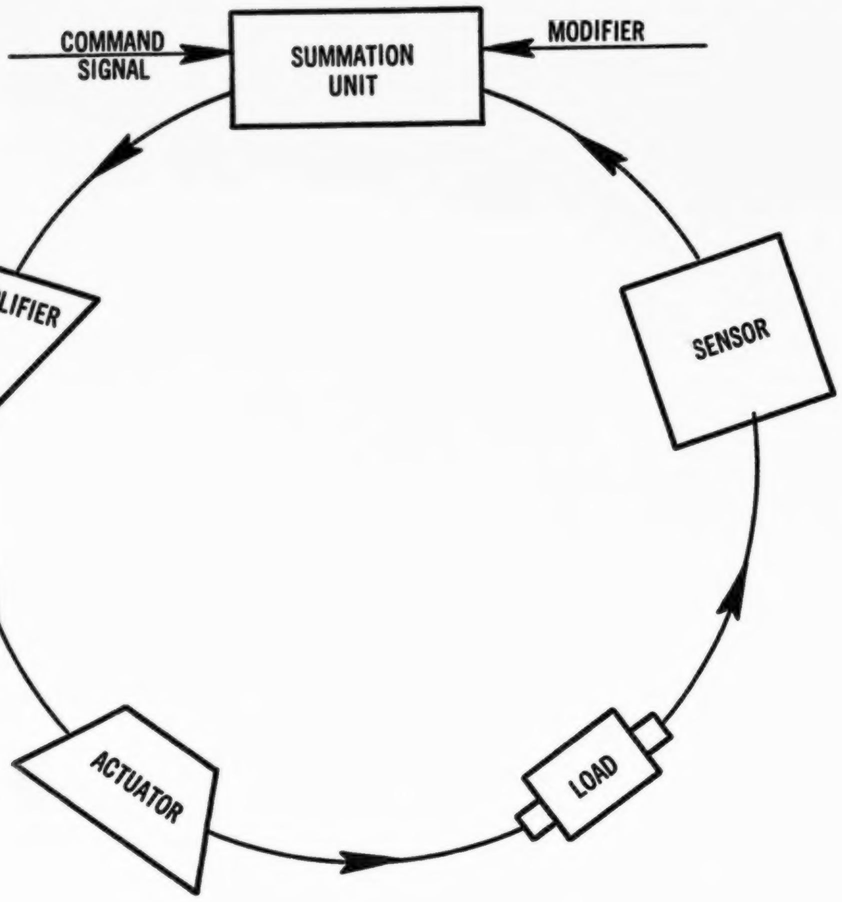


Fig. 3—2. The Basic Wheel of Control

- The summation unit exists to accept information from the various inputs. In N/C these are either electronic or mechanical. The electronic summation unit receives information from the reader and, in the form of error signals, from the feedback loop. Cutter offsets, speed and feed information, and other modifier inputs are fed into the system through the summation units. Mechanical summation units are often used in such forms as positive depth stops, speed range settings, and pressure or flow regulators. Hydraulic or pneumatic summation units may be in the form of regulators or relief valves, for example. The summation unit compares load conditions between the command input and the reports of the sensors, generating a signal which must be passed to the load for the correct action to take place. This output signal is usually referred to as the "error signal" even when it is the first command for movement. In that sense, to take a new initial position for the start of a new operation is to correct a positional error.

- The amplifying system is inserted to ensure that the error signal is transferred intact to the actuator with sufficient strength to be reliably recognized. Any form of circuit resistance must be overcome. A machinist might see circuit resistance as backlash that must be cleared from a gear train, or in terms of lead screw actuation. Examples of amplifying systems might include:

. . . . Mechanical: Levers, valves, variable speed drives

. . . . Electrical: amplidyne generators, magnetic amplifiers, relays

. . . . Hydraulic: differential pistons, servo-valves, intensifiers

. . . . Pneumatic: torque converters, pneumatic amplifiers, clutches

- The actuator provides the power to move the load, which in the case of a machine tool is the machine table axis being controlled by the system. It accepts the move signal from the amplifier and furnishes the required fluid, pressure, turns, impulses, or other energy output that causes the machine axis to make the required motion. Actuators can be stepping motors, heating elements, or solenoid operating devices, to name but a few. Belts, gears, levers, and linkages may be considered actuators where they use the energy transmitted to them to cause motion.

- The work table, which supports the piece of material on which work is to be done is commonly the load. It is the motion of this member or, in some configurations, of the tool with respect to the table that must be controlled and monitored. A great variety of physical relationships may be involved in the load; these relationships may range from a lathe tool bit moving longitudinally and crosswise against a rotating workpiece to a rotating drill with a solidly mounted workpiece changing position beneath it.

- The sensor monitors positions and conditions of the workpiece and feeds back corrective data to the summation unit for comparison. The sensor translates observed data from one physical quantity to another (e.g., a distance to a voltage) that can be accepted, understood, and acted upon by the summation unit.

Input Media and Storage

A machine operator who adjusts his machine to take a ten-thousandth of an inch cut does not know if that amount is actually removed unless he checks. When he checks and determines the amount of material removed, he closes the control loop. If his micrometer is replaced by a sensing device and the operator by a feedback loop, the operation is correctly termed automation. In order to have an N/C system, the earlier function of the operator in analyzing the blueprint and determining that a ten-thousandth cut is necessary must be incorporated into some input device. The first and second stages shown in Fig. 3-1 illustrate this functional part of the system.

In most N/C equipment the input is in the form of punched tape. Some earlier models use magnetic tape. With the appropriate reader, input may be in the form of punched or magnetic tape, punched cards, or manually operated dials. The reader converts the data received into a form that can be used by the control system logic unit. Originally, the codes for magnetic and punched tapes were different; at present, units being equipped with magnetic tape use the same code, in pulse form, that the punched tape carries in the form of holes. Magnetic tape is superior to punched tape in speed of encoding and reading.

Punched cards are slower to read than any form of tape and have the additional disadvantage of being easily mixed up.

Magnetic tape is read by an electromagnetic or electronic sensor. Punched cards and tape may be read by mechanical, pneumatic, or photoelectric sensors. Each has advantages and disadvantages. The quality and design of the tape are of prime concern if mechanical or photoelectric sensors are used. A mechanical finger-type reading unit produces greater wear on the tape and has a lower maximum speed. On the other hand, the photoelectric sensor requires a tape impervious to light. To overcome such disadvantages, a Mylar-coated tape with a core of aluminum foil or other opaque material has been developed.

With the tape in proper position and the reader started, all letters and digits encoded on the tape are read into the memory unit. The memory unit may be a series of stepping switches or some other component that registers in an on-off manner. When the load is ready for a new series of commands, the information stored in the memory directs the servo motors to drive the work table, usually at a rapid traverse rate, to the command position. Tool selection and auxiliary functions may be actuated at this time or when clearance is established and cutting motion is actuated.

From the initial position, the servo motors actuate lead screws coupled to the motor by timing belts, and the table moves as programmed. Selsyn pickup units attached to the screws send back table position information continuously. When the table and saddle arrive within one-half to one leadscrew revolution of programmed position, say within 0.050 inch, motors start to slow down. The tendency to overshoot is reduced by the slowing approach to the stopping point, and problems of hunting are minimized. When the table reaches the callout position, which has been verified by feedback, the motors stop and the table clamps.

Machines with automatic spindle feed may have the depth of the spindle controlled by tape. On such machines the spindle will not feed downward if the table has not gone to the correct position. To minimize backlash, ballbearing lead screws are installed, and automatic circuitry causes the table always to come to its final position from the same direction, regardless of the approach direction.

Control Malfunctions

Nonfunction. When the entire system simply fails to operate, time is lost, but there is no damage to machine or workpiece.

Dumping. Dumping may occur when the control is overloaded with a machine motion too fast for the reader or when the reader fails to read the tape correctly, as in the case of a "parity" error on the tape. Dumping can also be caused by voltage fluctuations, electronic malfunctions, or some other failure--for example, in the lubrication system. When dumping occurs, it is generally necessary to go back to the last previous programmed stop, although some

N/C systems have provided for this contingency a recovery capability that requires less time.

Electronic Failures. Electronic component failures, usually unpredictable, can cause serious damage. The cutter can fail to stop and cut through sides of parts, drill holes in machine tables, or run into the nearest clamp. In most plants, operators are stationed at the machine at all times to guard against this type of failure; and on the face of each control console is a prominent red stop button labeled "Emergency." Errors on N/C machines are most often of a gross type. Little errors seldom occur once the tape has been proved. The ones that do can usually be traced to operator failure in such things as tightening a cutter locking screw, setting cutter depth, or setting up at the set point.

Maintenance. System maintenance must be done by trained technicians. Improvements in the design of the "black boxes" such as printed circuits, increased use of solid-state components, and plug-in subsystems have reduced the time required for trouble shooting and the replacement of faulty parts by the service man. And more future systems will have built into them the capability to indicate which plug-in unit is at fault, thereby permitting immediate replacement and later repair.

INSTRUCTIONAL TECHNIQUES

References

Automatic Controls. Technical Education Curriculum Development Series. Sacramento: California State Department of Education, 1962.

Secrist and Journigan. Fundamentals of Machine Control Systems. Sacramento: 1962.

Zeines, Ben. Servomechanism Fundamentals. New York: McGraw-Hill Book Co., 1959.

Smith, H. A. "Organizing Maintenance for Numerically Controlled Machines," Plant Engineering (June, 1960), 111-13.

Specific machine tool and control system maintenance manuals.

Handout Materials

Manufacturers' brochures describing the essential features of their N/C systems. Available from manufacturers and distributors. Request on school letterhead.

Audio-Visual Materials

Automation, (No. 2801). Public Film Rental Library, University Extension, 2272 Union St., Berkeley, Calif. 94704. Rental.

Synchro Systems, Parts 1, 2. Film or filmstrip. United World Films, Inc.

Instructor Activities

Following lecture/discussion period, distribute a prepared list of sources from which assignments of the types listed under Student Activities can be made.

Student Activities

1. Prepare comparisons between present standard codes for tape (magnetic and punched) and cards.
2. Compare automatic, automated, and numerical control systems. Illustrate similarities and differences.
3. Diagram the Basic Wheel of Control.
4. Give examples of basic electrical, hydraulic, mechanical, and electronic units that perform the various functions of the control cycle.
5. Prepare a comparison, from available literature, of two competitive control systems, with respect to operating features, principles of construction, maintenance provisions, and control system logic.

unit 4
TOOLING

PLAN OF INSTRUCTION

Objectives

- To review conventional tooling practices and make the student aware of the changed needs resulting from incorporation of N/C
- To acquaint the student with trends in tooling standardization and interchangeability
- To introduce the student to concepts of preset tooling, proper tool application, automatic tool changing, and economical cutting tool selection
- To present to the student developments in materials handling, the newest methods in work locating and holding, and the machining center approach to material processing

Introduction

1. Define the difference between jig and fixture.
2. Discuss the purpose of tooling, carrying the discussion to the point where automatic tooling replaces conventional tooling. Evaluate why this is allowed to happen; then relate to N/C.

Presentation

1. Classify conventional tooling.
2. Illustrate examples of older and newer types of conventional tooling.
3. Illustrate N/C tooling and its relationship to conventional tooling.
4. Display tool holders for examination, and explain the automatic tool changer, illustrating common types.
5. Relate preset tooling to that used on turrets, automatics, and Kingsbury-type equipment.
6. Discuss tool maintenance, especially cutter sharpening and storage.
7. Relate changing needs and tool design developments.
8. Discuss changes in the occupations of tool and die maker and tool designer.

RESOURCE UNIT

The early development of N/C was prompted by the need of the aerospace industry, then in its infancy, for new machining techniques that would improve the precision of increasingly complex parts. The first breakthrough occurred during the development of improved equipment for checking precision parts at the Parsons Corp. What began as a means for checking conventional machine work revolutionized the production of the parts, instead of only the method of checking them. This is not a new story in tool development; the continuing effort of the tool planner, designer, and maker is to produce more efficient and effective tools.

Tooling Development

Tooling must be provided whenever a manufacturing need is translated into a practical application. Not many years ago, layout techniques were the accepted means for properly locating a hole or surface. For precision location of holes, toolmakers' buttons, jig borers, and jig grinders came successively into the picture. Holes in production parts were located using first fixtures and later drill jigs. To eliminate confusion that often results from use of these terms, it may be stated simply that fixtures hold the workpiece, while jigs both support the part being fabricated and locate the cutting tool.

The continued search for more accurate and efficient development of producing holes resulted in machines designed to combine the functions of jig and power source. Such machines have been most extensively refined and used in the building-block automation of the automobile industry. Holes can be produced best by performing a sequence of operations--center drill, drill, bore, and ream--before moving the part in any way. Development of removable drill bushings made it possible to extend this concept to drill jigs, and the high cost of such special jigs led to the development of general-purpose jigs and to reduction in the numbers of parts required for economical tool use.

Another problem of conventional tooling is that all of the special tooling must be designed and built before production can start. Lead time continues to be an important factor in the development of tooling and production methods. It is in this connection that N/C becomes very attractive, because with N/C little or no special tooling of a complex nature is required. The need for complex tools is replaced by the flexibility built into N/C systems. (See Fig. 4-1.)

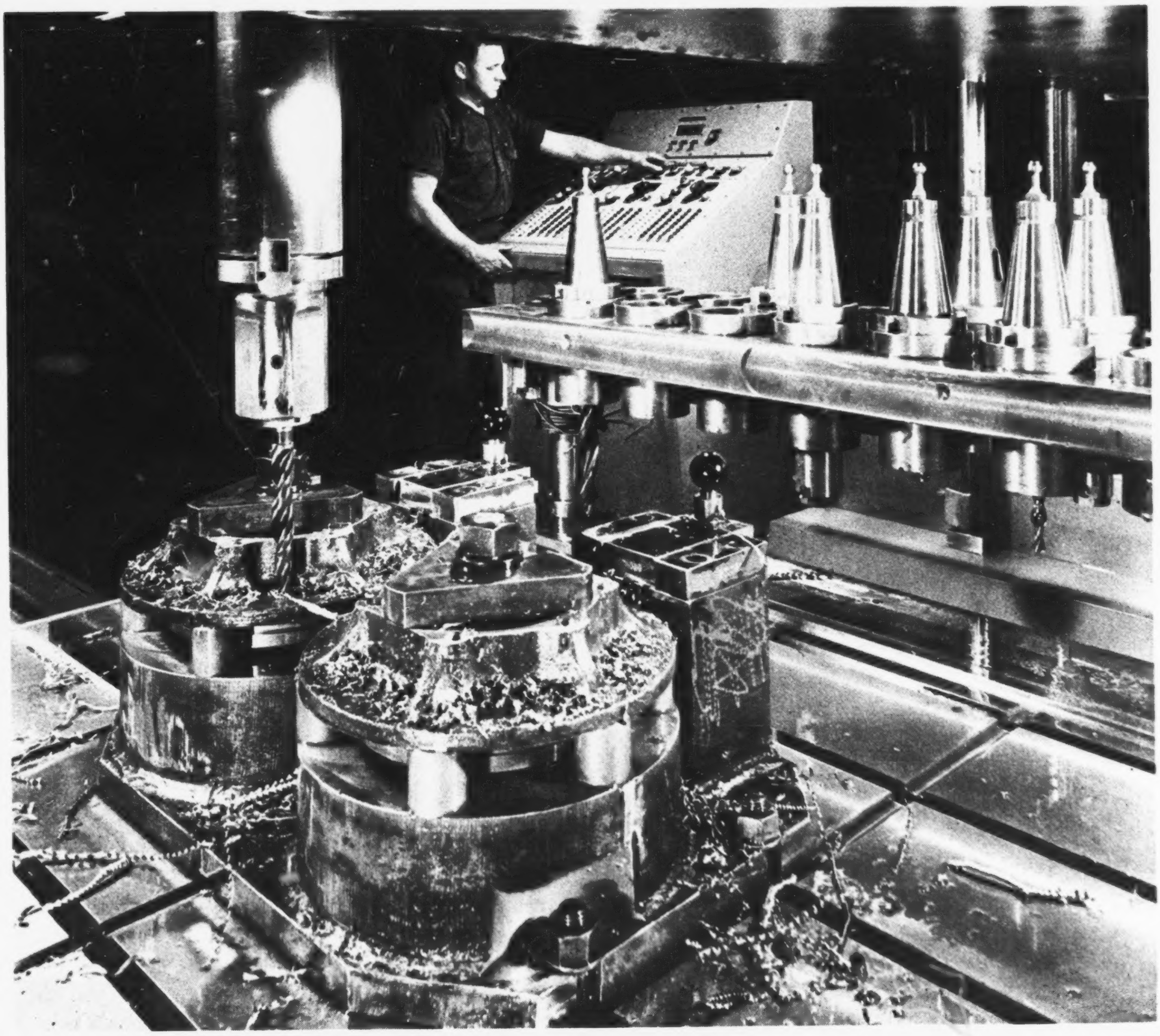


Fig. 4—1. A simplified work-holding fixture with adjacent cutting tool storage rack

Work-Holding Devices

The effective use of N/C equipment depends upon knowledge of the tooling choices available and of the factors involved in their use, such as cutting forces and equipment variables. Work-holding devices have been greatly simplified by the inclusion of the tool location function into the control system. Jigs are not needed, since the tool location is determined by the tape input data and monitored by the feedback system. A typical machine setup is illustrated in Figs. 4-2 and 4-3. The holding device used is simply a subplate fastened to the work table and equipped with suitable clamps, parallels, and riser blocks.

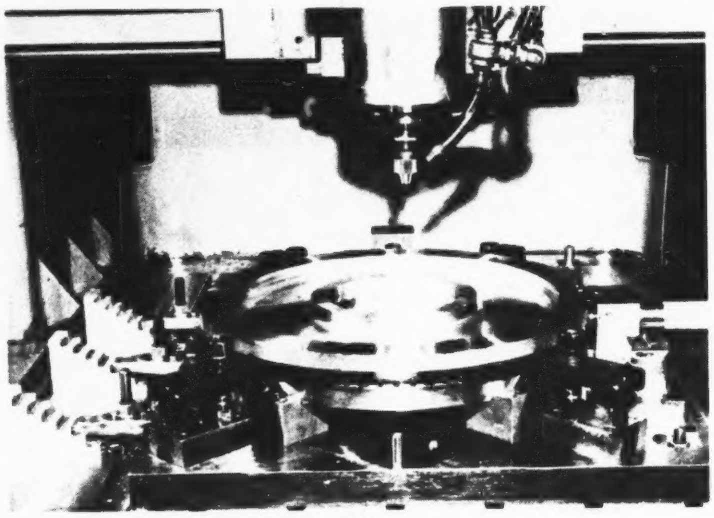


Fig. 4—2. Subplate type tooling with workpiece in position

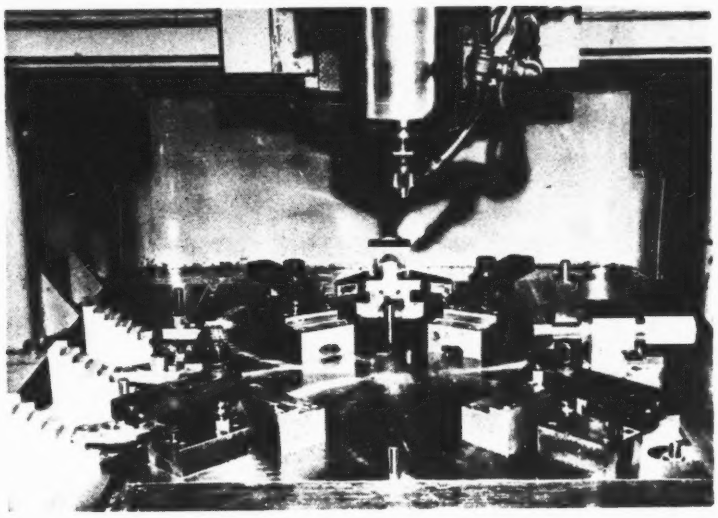


Fig. 4—3. Subplate type tooling with workpiece removed

Tooling holes can be drilled in plate stock cut larger than the part to be machined, allowing a clearance area for the holes. The holes are located and drilled on the machine that will be used to fabricate the part; often the same tape can be used to locate these points, together with location pins or expansion pedestals on the milling table. This provides accurate part location in all axes for as many operations as are necessary to complete the part. However, a disadvantage to this procedure is that the part must be cut from the tooling tabs and hand finished.

The riser plate or subplate technique, which uses precision-milled slots and locating holds, can be used effectively as a work-holding device. Plates are laid out in accurate one-inch increments (or in any convenient measurement pattern) from a setup point that is designated by the programmer in terms of the known dimensions of the riser plate and of the part to be machined. Tapped holes are made in the plate in numbers sufficient for the insertion of threaded studs and for the use of special or conventional clamping devices. Such plates may be made of materials as different as aluminum and hardened tool steel. (See Figs. 4-4, 4-5, and 4-6.)

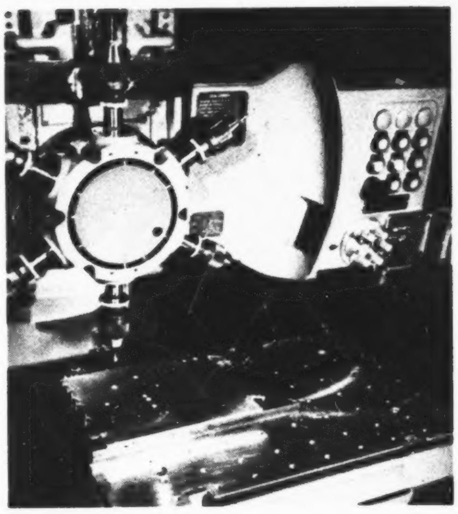


Fig. 4—4. Standard pattern subplate fixture mounted on drilling machine

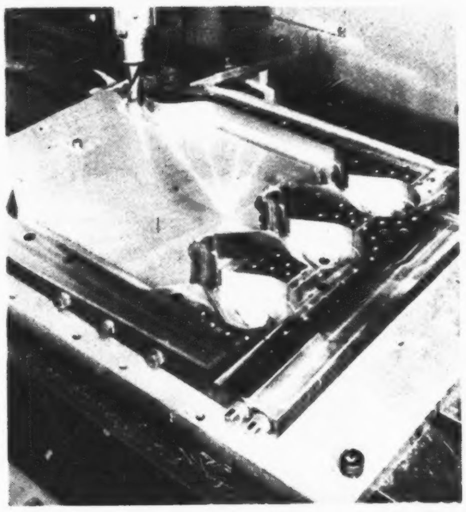


Fig. 4—5. Standard pattern subplate fixture mounted on vertical-spindle contouring machine

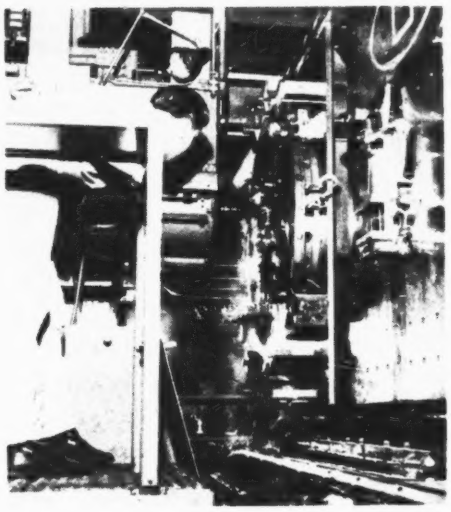


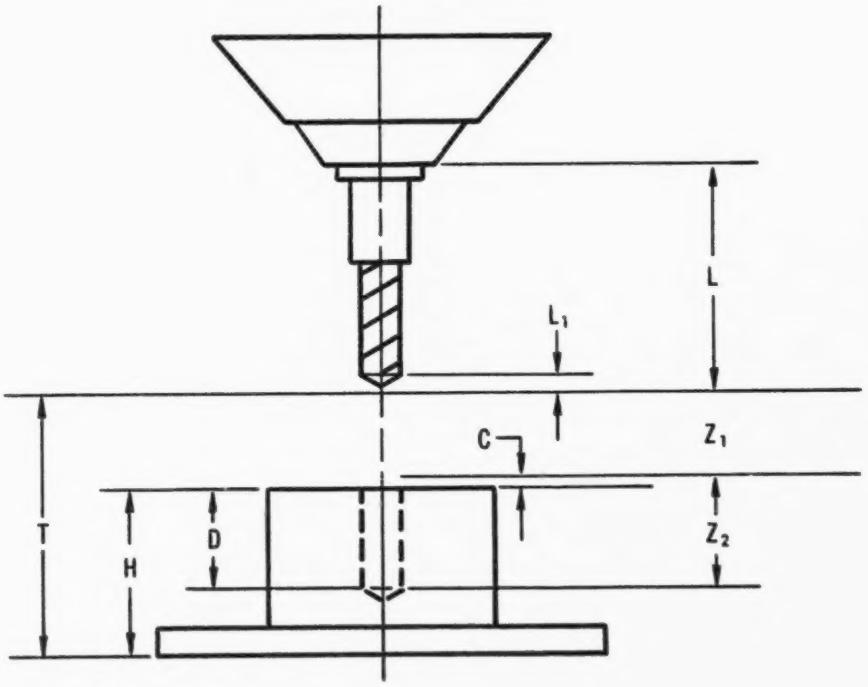
Fig. 4—6. Standard pattern subplate fixture mounted on horizontal-spindle contour-milling machine

Risers and subplates of this nature save the machine table from damage resulting from programming errors or axis overshoot malfunctions, if the operator is alert. Wear and tear from scratching and chip entrapment, as parts and fixtures are set up and removed, is minimized. And it is possible to program for drilling, boring, and reaming accurate locating pins on the same plate or on another to be attached to it.

Standard tools, such as vises, are limited in their application to N/C setups until accurate means of locating them on the table or subplate can be found. The dimensions of standard milling machine vises vary sufficiently so that preset tooling cannot be used.

Cutting Tools

The N/C method provides opportunity to preset cutting tools of all kinds with respect to length and diameter. Unfortunately, many machining teams do not understand cutter selection and use, including such basic aspects as feed and speed or surface finish control. Replacement of a dull tool with a substitute tool without any change in dimensions of the part being produced requires that standard practices be established. Fig. 4-7 shows the essential dimensions that must be considered.



L = PRESET TOOL LENGTH

L_1 = TOOL PARAMETER VARIABLE

H = HEIGHT OF PART AND FIXTURE AT POINT OF OPERATION

T = TABLE TO CUTTING TOOL (SETUP OPERATION)

D = DEPTH OF HOLE

C = CLEARANCE (TOOL TO WORK)

$Z_1 = T - H - C$ (RAPID APPROACH)

$Z_2 = D + C$ (FEED)

Fig. 4—7. Preset tool variables

Tools used on N/C drilling machines should be of a standard length to ensure proper setting for the depth of holes. This applies to settings for all end-cutting tools whose lengthwise spindle motions must be accurately controlled, particularly countersinks, counterbores, and boring bars. When new or first class tools are used, results are predictable, but with tools that have been sharpened or that have had their dimensions altered beyond very narrow limits, program changes are required. It is more expensive to make such changes than to use only standard-size tools. Many tools that are too far out of tolerance for use with N/C can be used in conventional machines or sold to others for such use, thereby retrieving some of their cost.

Cutting Tool Holders

A number of cutting tool holders on the market (such as Scully-Jones, Beaver, Weldon, and others) are easily adapted to standard machine spindles. Many manufacturers offer lines of interchangeable tool holders devised for N/C machine applications. Because of the wide variety of spindle hole possibilities, appropriate arrangements will be required to match the specified cutting tools with holders and adapters to fit the machine to which the work is assigned. Fig. 4-8 illustrates a typical preset tooling flow for N/C.

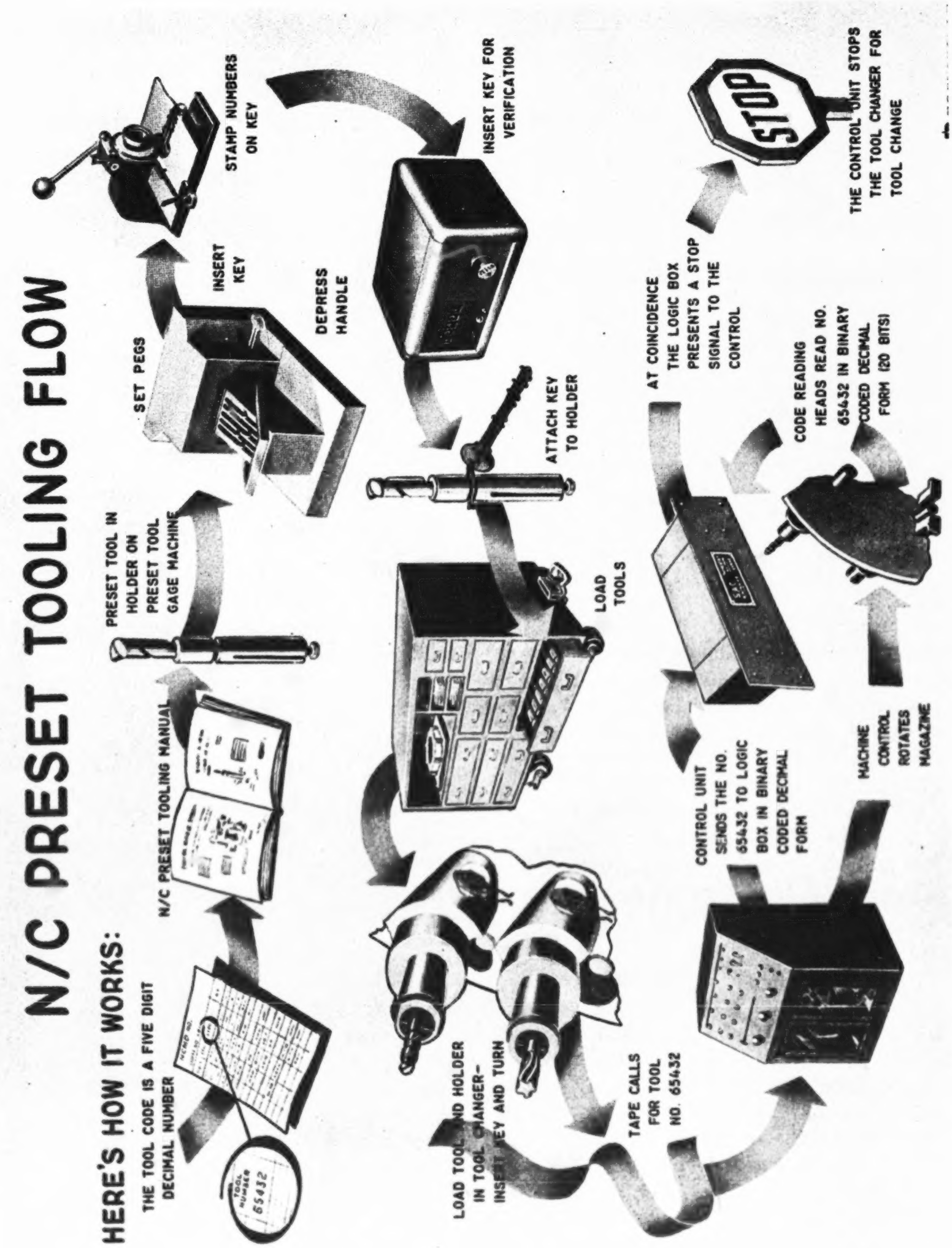

N/C PRESET TOOLING FLOW
HERE'S HOW IT WORKS:
THE TOOL CODE IS A FIVE DIGIT DECIMAL NUMBER
TOOL NUMBER 65432
N/C PRESET TOOLING MANUAL
PRESET TOOL IN HOLDER ON PRESET TOOL GAGE MACHINE
SET PEGS
INSERT KEY
DEPRESS HANDLE
STAMP NUMBERS ON KEY
INSERT KEY FOR VERIFICATION
ATTACH KEY TO HOLDER
LOAD TOOLS
LOAD TOOL AND HOLDER IN TOOL CHANGER–INSERT KEY AND TURN
TAPE CALLS FOR TOOL NO. 65432
CONTROL UNIT SENDS THE NO. 65432 TO LOGIC BOX IN BINARY CODED DECIMAL FORM
MACHINE CONTROL ROTATES MAGAZINE
CODE READING HEADS READ NO. 65432 IN BINARY CODED DECIMAL FORM (20 BITS)
AT COINCIDENCE THE LOGIC BOX PRESENTS A STOP SIGNAL TO THE CONTROL
STOP
THE CONTROL UNIT STOPS THE TOOL CHANGER FOR TOOL CHANGE

Fig. 4—8. N/C preset tooling flow

Some holders permit use of cutting tools that have been resharpened to greater minus tolerances from new dimensions. Figs. 4-9, 4-10, and 4-11 show a simplified tool-setting technique for which the spindles must be adaptable to a variety of holder configurations. A boring bar carefully preset, as illustrated, will give finished hole sizes within a few ten-thousandths of an inch of the specified dimension. The tool-setting skill of a competent jig-borer operator or horizontal boring mill operator is essential. With proper provision for alignment and checking, interchangeable replacement tools can be prepared and machine tool-change down time can be almost eliminated.

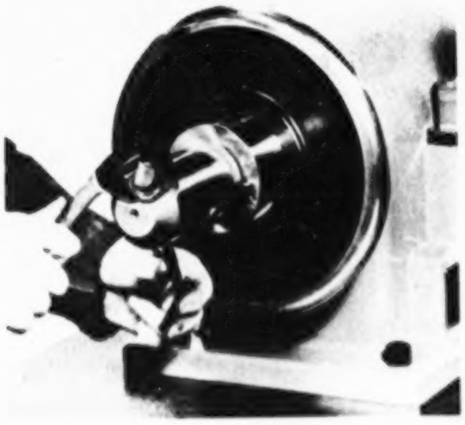


Fig. 4—9. Adjusting boring tool offset

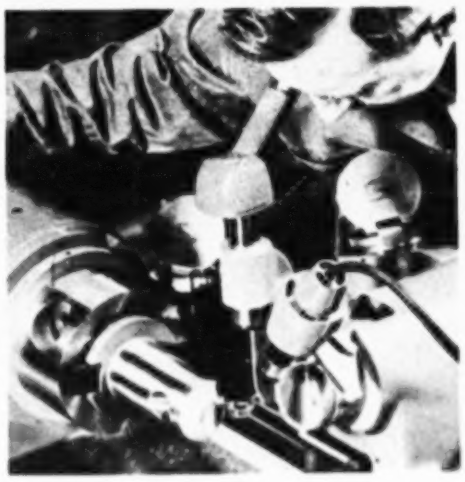


Fig. 4—10. Verifying boring tool offset with optical viewer

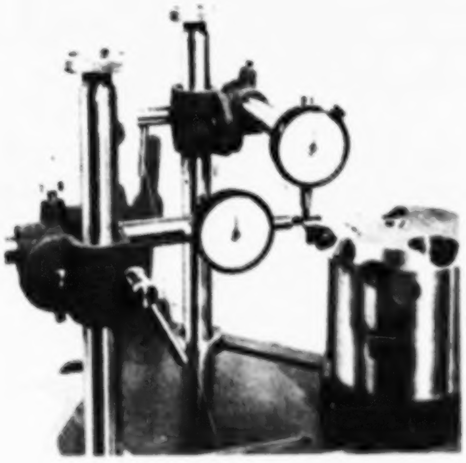


Fig. 4—11. Verifying boring tool offset with dial indicators

Two other applications of tool holders should be mentioned. Lathe tooling and special-purpose devices (such as tapping heads) are available, but neither is sufficiently standardized for N/C applications to be common. Each machine tool builder recommends individual tooling for his particular machine. Conventional quick-change tooling for lathes has not proven completely satisfactory for preset and programmed use. Tapping equipment available includes both automatic, without the need to reverse the spindle to remove the tap, and simple tap-driving holders that require special programming.

Milling Tools

Almost any form of cutting tool can be utilized in N/C machines; those most commonly used are drills and end mills. All N/C cutting tools must be of standard diameter unless cutter compensation devices are provided on the control console. The tooling follows a cutter path made up of a series of points. The points have been plotted by the programmer, possibly by means of a computer, who has assumed a specific cutter offset based upon standard cutter diameters. When necessary, roughing cuts can be made by substituting a cutter of smaller diameter or by setting the cutter farther away. But this technique is precarious unless the operator has some control of cutting speeds or unless specific instructions provide for the technique.

Conventional end mills are available with right- and left-hand spirals designed to permit control of the direction of cutting pressures and to provide for chip removal. Thus the programmer can choose the cutter that will direct the cutting pressure to suit best the holding device. The degree of spiral can be specified to provide some control of the cutter deflection that always occurs in end milling. The greater the spiral the more the deflection, but the cleaner the cutting action. Climb milling is often utilized, particularly for finishing cuts in aluminum.

Standard cutters are available with various numbers of cutting flutes. For all plunge-cutting applications, cutters must have end-cutting capability; two-flute cutters are widely used because they normally have this feature. Another advantage of two-flute cutters, particularly for cutting aluminum, is their larger chip clearance, with reduced likelihood of loading up. Four-flute cutters are more rigid and have less tendency to deflect under cutting stresses. Wherever a long cutter is required, four or more flutes are recommended because of the larger web section of the cutter. End-cutting features can be ground on multi-flute cutters, but they are not as efficient as on the two-flute type.

Shell end mills and mills having inserted tooth segments have not been widely applied in N/C machines, probably because most N/C work has been on aluminum. Moreover, the part sizes and the tool holders used have not been suitable for larger cutter diameters. Most surfaces involved in contouring require many passes of the cutter and the larger face surfaces of these types of cutters would only be in the way. Some ball mills and special-angle cutters are being used, but most of the work is being done by standard cutters with specified radii.

The Machining Center

It was inevitable that the achievement of quick change tooling would point to the possibility of automatic tool changing. The latter was first applied in Milwaukee-Matic machines and has since been incorporated into machining centers developed by Sundstrand, Hughes, and others. These machines make possible, for the first time, almost complete finishing of machined parts in one series of motions and tool sequences. They depend upon an operator for tool changing only under unusual conditions, such as when running two different parts alternately from different tape readers, a procedure that involves almost continuous operation of the cutting tools.

Each machining center unit incorporates a tool magazine, one form of which is shown in Fig. 4-12. Use of the magazine depends upon tool coding, discussed later in this unit.

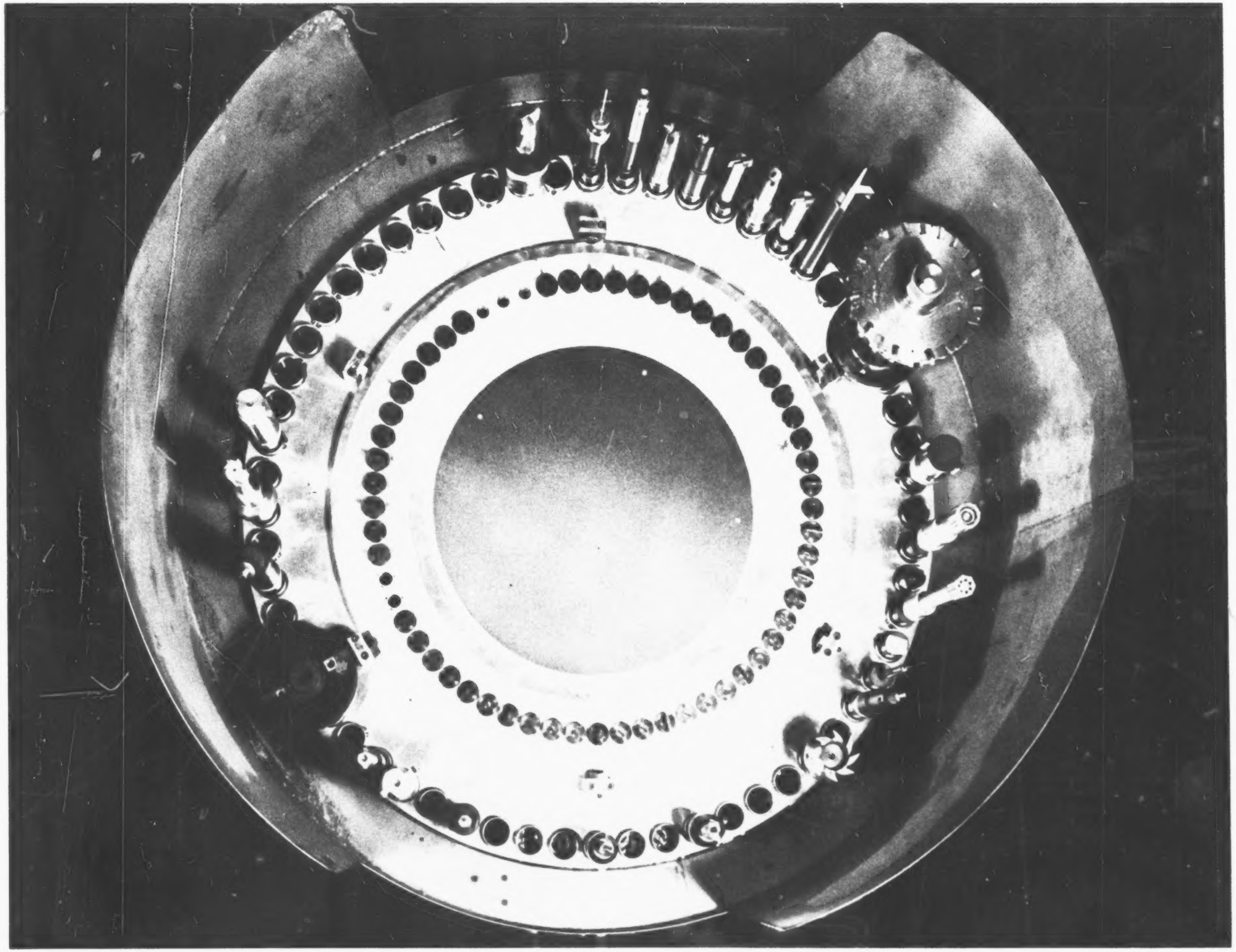


Fig. 4—12. A machining center tool storage magazine (key code type)

N/C operations that require one or more tool changes commonly have the tools conveniently racked in the machine area, as illustrated in Fig. 4-13. Two or more of each tool are provided; as one is dulled, it is replaced by a duplicate.

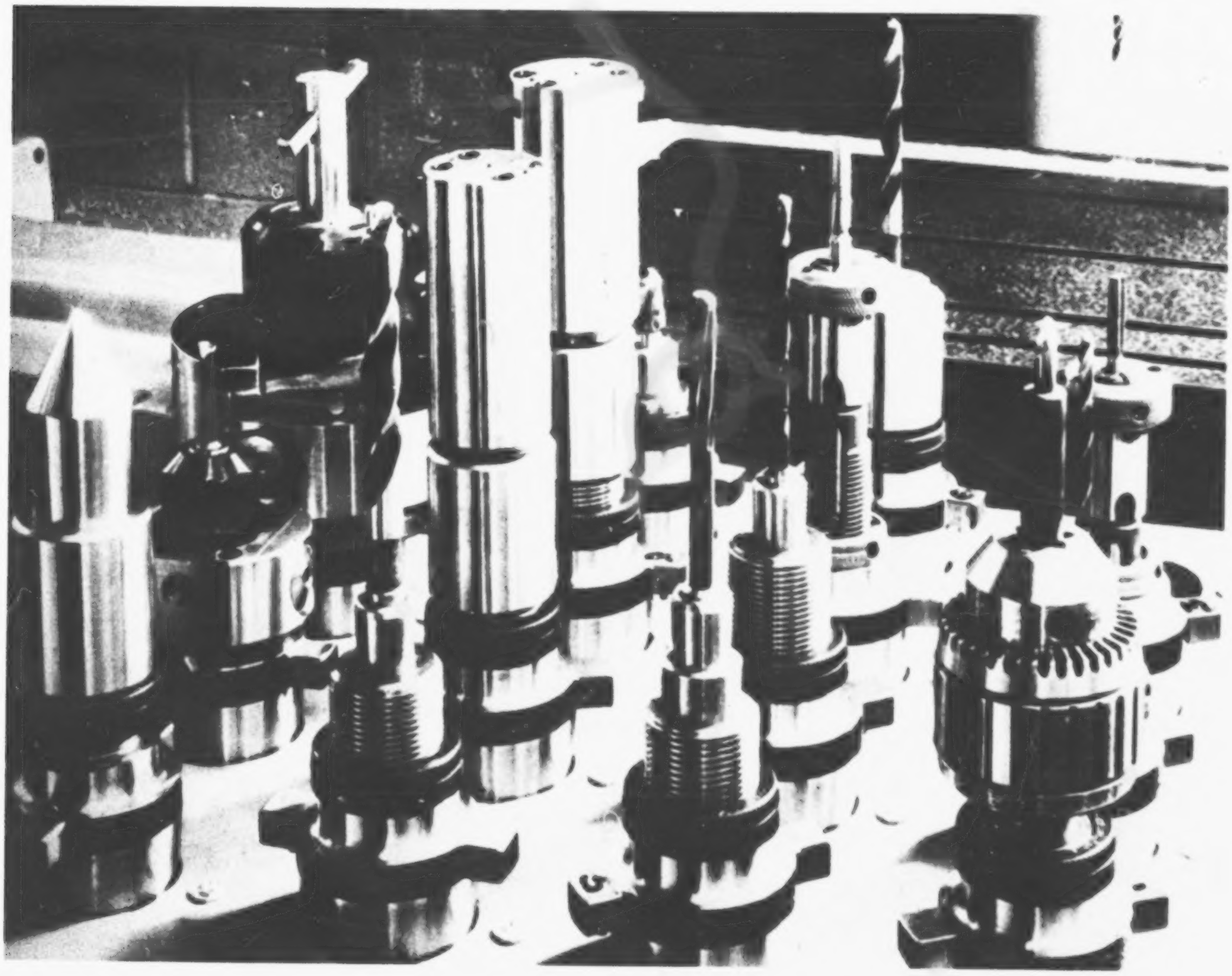


Fig. 4—13. A manual tool insert storage rack

Tool Codes

The tooling coordination program, depicted in Fig. 4-8, provides for early assignment of tool code numbers. Three basic coding systems now in use permit tool selection to be programmed. In the first system, each tool is placed in a specific position to which it is returned after each use, as in the turret setup of Fig. 4-14. The second system uses a ring coding method developed by Kearney and Trecker Corp., shown in Figs. 4-15 and 4-16; and the third, developed by Sundstrand, involves the use of an interchangeable key and cartridge system, shown in Figs. 4-17, 4-18, and 4-19.

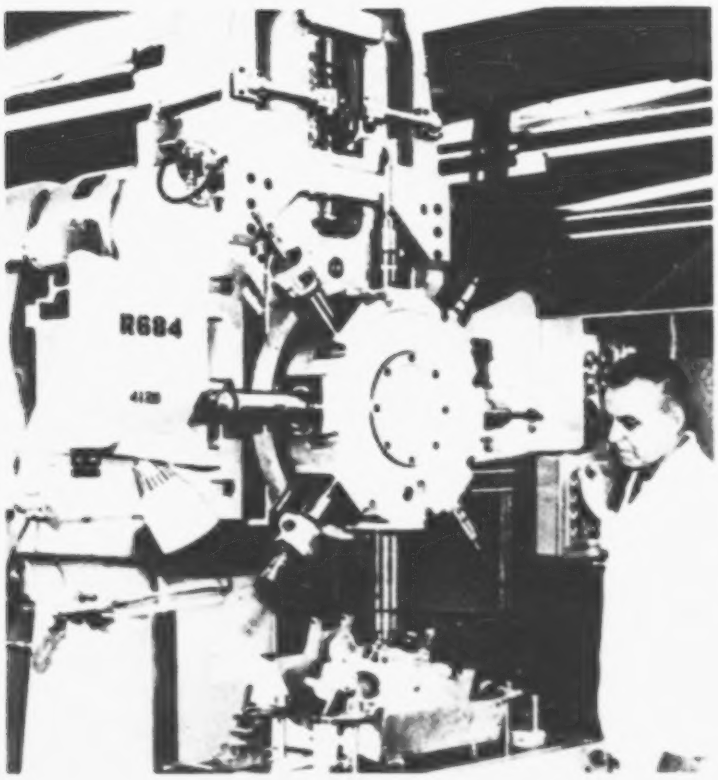


Fig. 4—14. Turret-type tool positioning

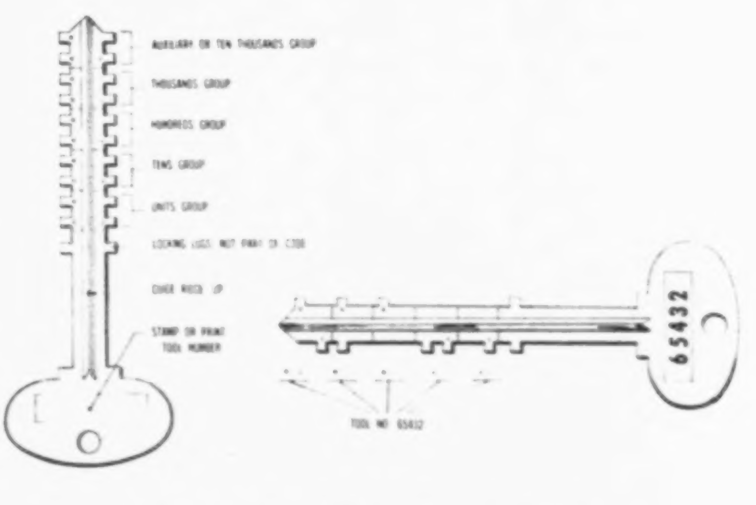
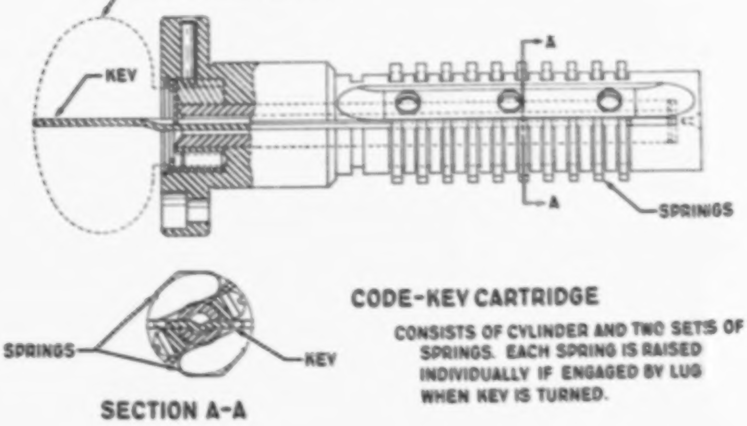

AUXILIARY OR TEN THOUSANDS GROUP
THOUSANDS GROUP
HUNDREDS GROUP
TENS GROUP
UNITS GROUP
LOCKING LUGS NOT PART OF CODE
STAMP OR PRINT TOOL NUMBER
65432
TOOL NO 65432

Fig. 4—17. N/C key code system


KEY IN READ POSITION
KEY
A
A
SPRINGS
SPRINGS
KEY
SECTION A-A

CODE-KEY CARTRIDGE

CONSISTS OF CYLINDER AND TWO SETS OF SPRINGS. EACH SPRING IS RAISED INDIVIDUALLY IF ENGAGED BY LUG WHEN KEY IS TURNED.

Fig. 4—18. N/C preset tool key cartridge

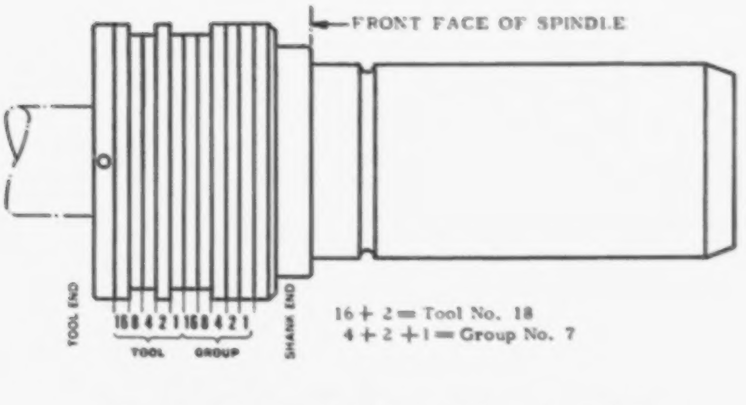
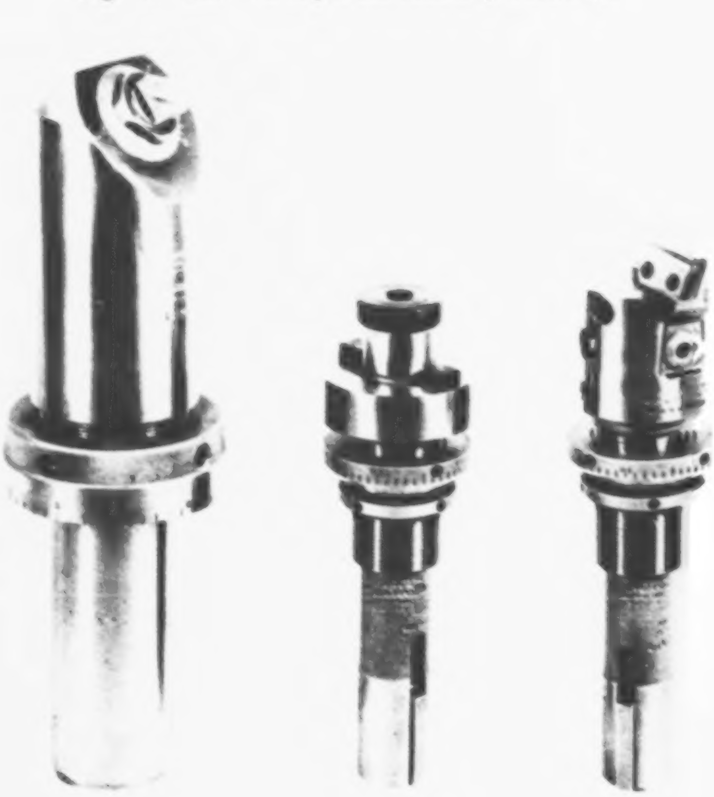

FRONT FACE OF SPINDLE
TOOL END
16 8 4 2 1 16 8 4 2 1
TOOL
GROUP
SHANK END
16 + 2 = Tool No. 18
4 + 2 + 1 = Group No. 7

Fig. 4—15. Coding rings, Milwaukee-Matic tool holders



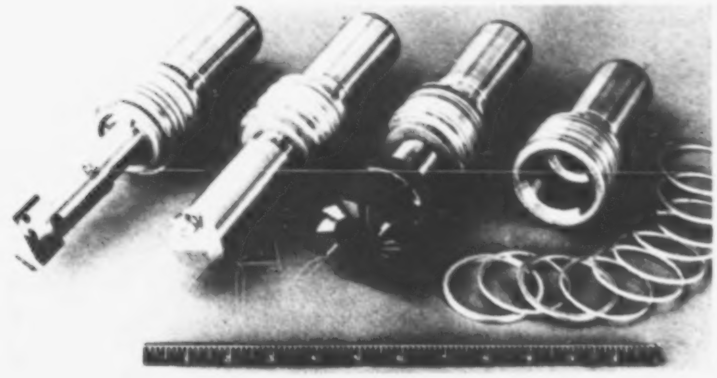


Fig. 4—16. Milwaukee-Matic type tool holders and coding rings

Fig. 4—19. Tool holders with key code identification

The newest coding systems use, in the arrangement of raised ring or key portions, a form of binary coding that can be read by the machine tool as it seeks a specific combination. The ring-coded tool can be replaced in any position of the magazine; the key-type must be returned to the position where the key has been inserted. Coding errors are avoidable only through meticulous attention to detail in the encoding process.

Tool Planning and Design

The emphasis on tool planning has shifted from work-holding fixtures to the maintenance of tool-coding procedures and their proper designation in standards manuals. This is indicated by the sequence illustrated in Fig. 4-8. The information included in operators' instruction sheets, control tapes, tooling lists, fixture-handling instructions, and setup information must all be precisely coordinated. Cutters must be sharpened and maintained to strict specifications. The problems of tool and cutter grinding are receiving increased attention in N/C research and development.

With greatly simplified fixture design, tool planners and programmers will have to work very closely together to ensure the specification of efficient cutter paths and proper tape preparation. It is sometimes, but not always, feasible to use the production tape to prepare the fixture. In many cases, a modified or even simplified variant of the production program will do. Tool drawings themselves can often be replaced by simple sketches; detail parts will be standard stock components. Hence, detail drawings will not be necessary. But step-by-step procedures for fabrication may be needed to coordinate the thinking of the tool planner with that of the person making a fixture.

Occupational requirements for tool planner and tool maker have not yet changed drastically. Much conventional tooling is still in use, but as time goes on fewer complex jigs and fixtures will be needed. Meanwhile all tooling personnel should be made aware of the capabilities and requirements of the new technology. New knowledge will be needed to perform usual tooling functions rather than to cope with new functions. Experienced tool makers and tool planners will best be able to incorporate the elements of skill, judgment, and decision-making into instruction sheets, control tapes, and programs. The revolution in tooling techniques will change the functions of tooling manufacture greatly, improving the quality and increasing the output. It will also sharply increase the knowledge required of people in this field and change dramatically the way they spend their work days.

INSTRUCTIONAL TECHNIQUES

References

Clarke, Robert E. Methods of Training Plant Personnel for Numerical Control. Paper presented at the Annual Meeting of the American Society of Tool and Manufacturing Engineers, held at Chicago April 29 to May 3, 1963.
Wilson, Frank W. Numerical Control in Manufacturing. New York: McGraw-Hill Book Co., 1963.
Selected reprints from American Machinist, Machine and Tool Blue Book, and Tool & Manufacturing Engineer.

Handout Materials

Sample tool plan
Sample route sheets (blank)
Part drawing with hole pattern to be drilled
Tool catalogs for cutting tools, interchangeable tooling, and quick-change tooling

Audio-Visual Materials

A Simple Approach to Flexible Automation. Sound, color film, 30 min. Burgmaster Corp., Gardena, Calif.
Samples of ring code and key code tool holders
Sample N/C machined parts, with right- and left-hand versions, if available

Student Activities

1. Working from part drawing, plan a conventional route sheet, including complete tool callout, jig and fixture callouts, and operation performance sequences.
2. Make tool sketches for each of the jigs and fixtures called out.
3. Replan one phase of the part production for N/C, including as many conventional operations as can be included in a single setup.
4. Prepare complete tool planning, including cutting tool callout and fixture plan.
5. Prepare a fixture plan for an other-hand version of the part plan assigned.
6. Describe, using a sketch, how a full radius cutter is used to produce contours.
7. Describe in detail, with sketches, the applications of right- and left-hand spirals on cutters and the reason for using climb milling to finish aluminum.
8. Prepare a tool code specification sheet, and explain the relationships involved in a preset tooling program.

unit 5

MACHINE OPERATOR'S RESPONSIBILITY

PLAN OF INSTRUCTION

Objectives

- To identify the changing relationships involved in the job of machine tool operator
- To familiarize the student with the communication media utilized in defining work to be performed
- To acquaint the student with operator's manuals for N/C equipment and to develop a usable vocabulary for interpreting the information presented

Introduction

1. Review operator's duties in a conventional assignment.
2. Illustrate a typical job assignment for an N/C machine, and describe procedure.

Presentation

1. List operator's skills essential to conventional operation methods.
2. Evaluate N/C duties for residual and new skill requirements.
3. Illustrate a machine operator's instruction sheet.
4. Present N/C drawing and setup drawings.
5. Discuss printout forms and tape formats.
6. Describe tape readers and handling tape, including rewinding, storage, and related problems.
7. Describe setup techniques, tool installation, and machine alignment.
8. Discuss operator's duties and responsibilities during machine operation; detail malfunctions.
9. Discuss operator's responsibilities with respect to finished part and his responsibilities for tape proving, inspection, and scrap.

RESOURCE UNIT

Increased utilization of numerical control of machine tools will affect the number of machine operator jobs available, as well as affect the kind of work done by the operator. Replacement of several conventional machine tools by a single N/C tool is a normal development, accelerating since the early 1950's. The most expensive way to produce an item is by machining, and a machined part is worth the price only when no other practical way to do the job exists. Much work, traditionally done in a machine shop, has been accomplished by using other processes and materials to produce an equivalent result. Numerical control, on the other hand, acts to return much work to machine shops by reducing the cost of parts produced. In addition, N/C has demonstrated capability for doing several classes of work that cannot be accomplished productively on conventional equipment.

Changes in Operation Requirements

The experiences of companies that have changed over to N/C vary widely. Some think that necessary operator skill has been greatly reduced and that setup and control duties can be done by the parts programmer when those duties are not performed by the machine itself. Other companies, after careful evaluation, have concluded that the greatest productivity increase comes when highly skilled machinists operate the equipment; the operator of N/C equipment needs many of the basic skills that are required to operate conventional equipment, plus additional skills unique to N/C.

The operator of a conventional machine plans and sets up the correct sequence of machining operations; he interprets blueprints, fabricates outlines, or makes route sheets as necessary. He selects and manually adjusts such variables as feeds and speeds. He controls the directions and distance of table travel by the use of manual, semiautomatic, or automatic controls. He is responsible for mounting and alignment of tooling, which he often selects and sometimes fabricates himself. He loads the workpiece, tends and adjusts the machine during the operation, and unloads the work at completion. He is responsible for measurements of the workpiece before, during, and at completion of the operation, and for making such adjustments in machine aligning and positioning as will produce parts within specified tolerances.

The skills and knowledge required to accomplish the foregoing on a conventional machine include, in part, knowledge of general shop and machining procedures, ability to read blueprints and engineering instructions, and knowledge of shop mathematics, including necessary trigonometry. The operator of an N/C machine needs to know considerably more. He needs to know enough programming to understand manuscripts and something of coordinate axial notation as it appears on manuscripts that illustrate the information coded on the control tapes. He must understand the starting and stopping sequences, and how to interpret instructions for setup, tool change, and other functional duties.

Although the N/C operator no longer pulls the handles, often more know-how is involved in pushing the right button at the right time. Both the equipment and the parts produced are expensive, and many companies prefer to assign only the most highly skilled and experienced machinists to work on tape-controlled equipment. And installations such as the machining center call for vastly more skill in operation than a single-spindle drill press or a punch. Management attitudes toward job classification vary with the types of equipment utilized and the complexity of the parts produced.

Safety

Comparison of conventional and N/C operation would be incomplete without a comparison of the safety factors involved. Safety is the result of knowing the machine and applying common sense to the performance of the work assigned. N/C machines are usually more powerful, faster operating, and more sensitive to errors than conventional machines, and the specific sequences established by the programmer must be maintained to ensure a satisfactory rate of production of high quality parts.

The N/C machine is to a large extent self-controlling, and the temptation for the operator to turn his back is great. The first rule of safe operation is to keep the operator close to the emergency button. Coffee breaks and other interruptions should be deferred until program stops, and nonprogrammed shutdown should be avoided whenever possible.

Operator reaction time is often all that prevents extensive damage. Operators must therefore be alert to malfunctions of any kind. Above all, they must be thoroughly familiar with the control console and with all of the operator options provided thereon.

The injuries most frequently reported around N/C machines are falls, headcuts from coming up into overhangs, and chip cuts. There are others, of course. The following safety precautions should always be observed to prevent accidents and injuries:

- Provide guards; N/C machines are usually high-speed machines.
- Operators and observers wear safety glasses at all times.
- Check tooling depth setups before installation.
- Make tool depth setups with the spindle stopped.
- Keep chips clear of moving parts. The large amount of chips produced requires constant attention and adequate chip-handling facilities.
- Keep the work area clean and orderly in all respects.

Machine Operator's Instructions

Machine operators are usually furnished a box or tray containing an instruction sheet, holding fixtures, control tape, cutting tools, work order, and a blueprint of the part to be machined. (A copy of A Typical Set of Operator Manual Instructions will be found as Handout Sheet No. 5-2 at the end of this unit.) The material to be worked is normally accompanied by a copy of the shop routing (Handout Sheet No. 5-1), which shows operations that have been performed and those that are to follow. The operator verifies that all materials are correct for the job and operation, including the proper tape and tape printout. It is the operator's responsibility also to measure the cutting tools for proper diameter, overall length, flute length, corner radius, and sharpness of the cutting edge. When any part must be scrapped as a result of using wrong cutting tools or dull tools, it is considered the operator's responsibility.

The Operator's Instruction Sheet (Handout Sheet No. 5-1) gives information as to the proper tools and fixtures or holding tools. It also tells the part number, the number of pieces to be machined, the machining procedure, the shop routing, and the setup instructions. The setup instructions may be accompanied by or in the form of sketches. Correct location of the fixture(s), correct console settings, and alignment techniques are given. The form of the operator's instructions is not standardized, but it generally conveys at least the foregoing information.

Where computers have been used to calculate the coordinate values, printouts may be included in the kit. Often the alpha-numeric tape punch will make a printout as the tape is prepared. It is not uncommon to file the master tape away from the shop area and produce duplicates automatically for shop use when needed. When the control tape is made, a printout which can be sent to the shop is obtained.

Tool Change and Setup Instructions

The setup sketch (as illustrated in Handout Sheet No. 5-1) gives complete instructions for producing the locating nest for the parts, in terms sufficiently exact to facilitate placing the fixture or preparing the locators. The precise location of the set point must be indicated. The positions of the clamps are usually specified also. These positions are often critical, since the tape program is fixed. The tape will return the cutter to set point when it is necessary to change the tool or reset the clamps.

The manuscript and the tooling list, included in Handout Sheet No. 5-1, also accompany the setup sketch to indicate the exact coordinate movements and to give all necessary information for presetting the cutting tools and for tool changes. In other columns further information is provided:

Column g - Preparatory functions, such as rapid traverse, dwell, spindle reverse, retract, and the like

Column m - Miscellaneous functions, such as coolant off and on, tool offset, stop, and the like

Column t - Tool size

Column f - Feed rate

Column s - Spindle speed codes

Column n - Numbered information about each numbered hole on the sketch

For the manuscript illustrated, the instruction columns, the tool description sheet, and the drawing make up the setup and operation instructions to the operator. A more complex format might be required for more complex machines or jobs.

Tape Proving

The most critical phase of N/C machine operation is checking out a new tape. This procedure, called "tape proving," involves critical analysis of the programmer's work, as well as testing out everything that has been prepared to guide the operator and the machine tool in producing that job. The operator must monitor every movement of each of the machine axes and must be alert to detect any chatter or other irregularity during cutting operations. When feed rate overrides are provided on the console to permit feed rates to be reduced at critical stages, the operator should note the correct reductions on the instruction sheet.

Even minute errors, such as misplacement of a comma in the manuscript, can cause omission of a feed rate change or flow of the wrong coolant. The time to catch these mistakes is during tape proving. When the tape proving is completed, the instruction sheet will show all manual dial-ins required by the operator. The programmer reviews all errors noted by the operator and corrects all that are critical. If cutter paths or some other phase of the operation can be readily corrected by manual dial-in, the tape may not be rerun, particularly if computer time would be required.

Making the Setup

The setup starts with the operator reading and understanding the setup instructions. He identifies all clamping equipment and verifies the cutters furnished with the setup kit. He installs the tape in the reader and aligns the machine to the setup position. The specific method of aligning the machine varies from one make of machine to another. A common procedure is to actuate the tape, which moves the machine table to the defined setpoint and makes a programmed stop. The first tool can then be installed.

In most setup sequences the fixture must be installed before cutting tools are installed. A fingertip indicator is used to sweep in the hole located in the center of the set block. Longitudinal alignment may be accomplished by means of keys in table slots or alignment pins in a standard subplate. These procedures apply to machines that use absolute systems of reference for noting machine motion. On these the setup point has a specific value in terms of distance from the ends of motion of each axis.

Other machines use the incremental system of movement, in which each motion is called out with reference to the last position: X=3, Y=5 would designate a point 3 and 5 units from the last point, not necessarily from the intersection of the axes. When incremental callouts are used, the "floating zero" is convenient. Using this device, the operator may simply place the fixture on the table and align it, sweep the spindle in on the setup point, install the cutter to the correct zero depth, and actuate the tape. The problems of alignment and tool installation are clearly in the province of the operator. He must be thoroughly familiar with the correct procedures for any machine he operates.

Tool installation also varies with the make of the machine. Where there are tool magazines, tools are placed in the correct sockets with the signal key, when required, inserted properly. It is essential to check tooling codes when tools are installed; no means is provided for the machine to sense an error in code designation. Serious damage to machine and workpieces can result from carelessness at this time. When cutters are inserted into turret positions or coded manual-load racks, the same care must be taken. Each tool must be depth-set to a prescribed zero position.

During tool installation, manual dial-in controls are used to move such things as Z axis and turret position for easy access. When the sequence of cutting tools has been established, a full cycle of the tape is run. For some very complex parts, or on one-of-a-kind jobs such as large dies, styrofoam or the like may be used for the tape-proving and checkout runs. Where each tool is a manual load, depth settings are made at program stops, much in the manner of setting up a turret lathe. Each cycle is then supposed to reproduce identical cutter positions.

Responsibilities During Operation

During the cutting operation, the operator must anticipate each move of the machine in order to recognize error or malfunction before damage can result. He must monitor the motion in each axis, change cutters at appropriate program stops, and reset direction of rotation and turning rates when changes are called for. He must ensure correct application of coolant, redirecting nozzles as they are disturbed by flying chips. In general, he acts like any machine operator--loading and unloading parts and checking dimensions, cutting action, and surface finishes.

But the N/C machine operator has only limited control over the motions made and dimensions produced. He is a standby control system "for emergency use only," and other duties assigned that are to be performed during cutting operations he must accomplish within reaction distance of the emergency button. These other duties regularly include deburring finished parts, checking dimensions, and checking condition of the parts. In many installations the N/C machine operators disassemble preset tools from previous operations and install into holders spare tools to be used as replacements for tools which become dull.

Responsibility for Quality

In the final analysis, the machine operator is chiefly responsible for quality. If dumps occur or a part is spoilt by any other form of machine malfunction, the resulting incorrect or scrap parts are not counted against the operator. But the operator is supposed to correct variations in hole sizes or other features of parts that should be identical or to call attention of his supervisor to the differences, and the attentiveness of the operator is relied upon to prevent or minimize any scrappage due to incorrect or dull tools. In many plants the operator is expected to make a quick check on the finish and quality of each part run. In some plants he may not run a second part until the first article has undergone a regular check by an inspector. Occasional detailed checks of finished parts are essential, even though an N/C machine may have to be stopped until the part is checked.

INSTRUCTIONAL TECHNIQUES

References

"Train Students Early for N/C," Iron Age, (January 24, 1962).
Operators' Instruction Manuals, available from machine tool manufacturers and distributors
Miscellaneous reprints from periodicals
Textbooks on machine shop theory and practice

Handout Materials

Fabrication Outline Forms (5 pp.) (Handout Sheet No. 5-1)
A Typical Set of Operator's Manual Instructions (Handout Sheet No. 5-2)
Copies of machine setup and operation manuals for various N/C tools, as available

Audio-Visual Materials

New Sounds of Tape. 16 mm. color sound film. 30 min.
Tool Changer. 16 mm. color sound film. 30 min.
Jig Borer. 16 mm. color sound film. 18 min.
All available on free loan from Dayton and Bakewell, 1950 Lovelace Ave., Los Angeles, Calif. 90015.

Instructor Activities

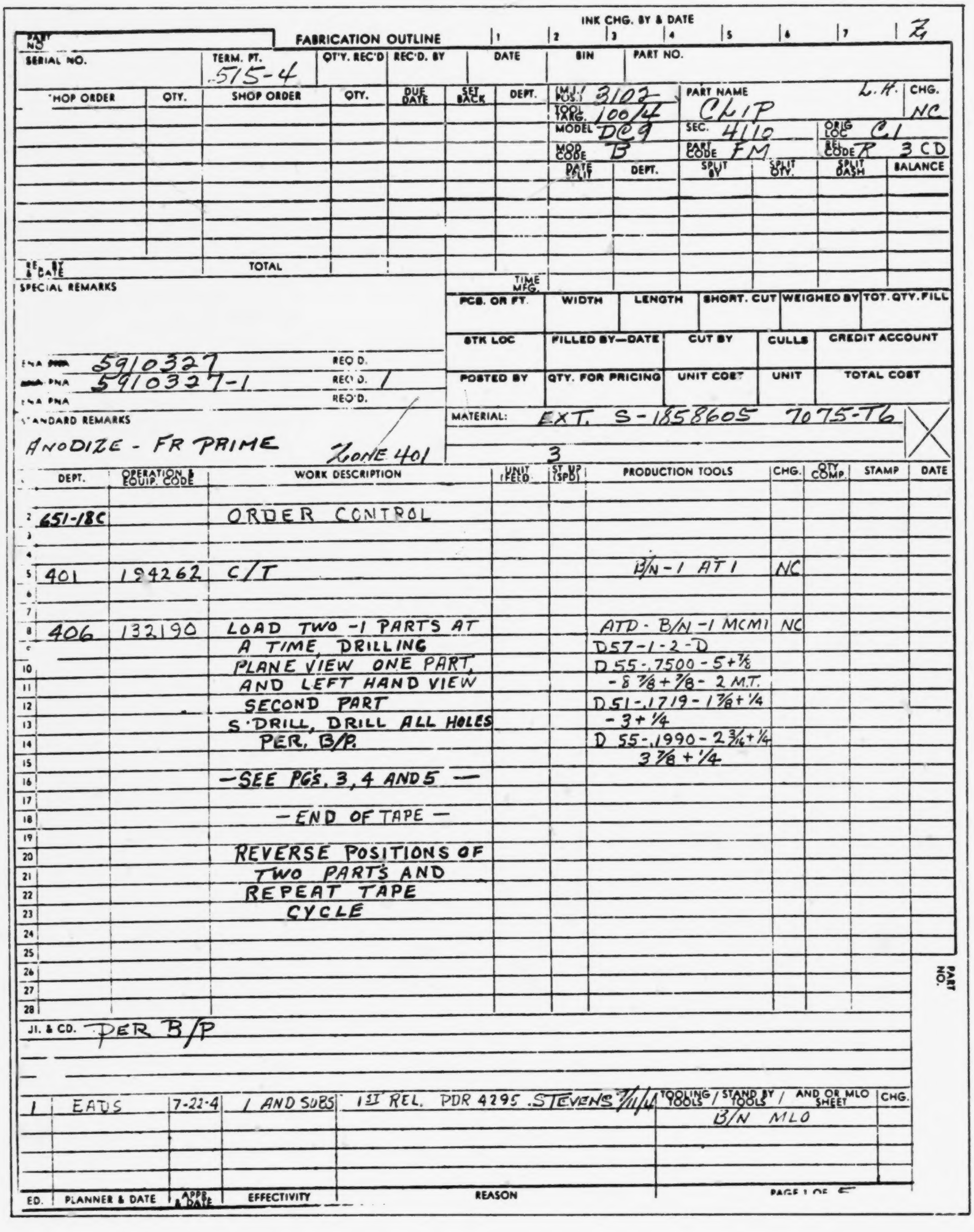
Arrange a field trip for students to see N/C machine setup and operation.

Student Activities

1. Prepare a conventional shop routing sheet, using part described in Handout Sheet 5-1 or another similar part.
2. Plan setup instructions for conventional operation and for a comparable N/C operation. Identify differences and similarities.
3. Prepare complete set of operator instruction sheets for sample parts.
4. Participate in a field trip to see N/C machine setup and operation.
5. If machine tool is available, prepare a setup and operate under supervision, using class-prepared instruction sheets.
6. Using a completed part, outline the probable tooling, machining methods, and operator's instruction sheet.

Handout Sheet No. 5-1

FABRICATION OUTLINE FORMS



PART NO

FABRICATION OUTLINE

INK CHG. BY & DATE 1 | 2 | 3 | 4 | 5 | 6 | 7 | Z

SERIAL NO.	TERM. PT. 515-4	QT'Y. REC'D	REC'D. BY	DATE	BIN	PART NO.

SHOP ORDER	QTY.	SHOP ORDER	QTY.	DUE DATE	SET BACK	DEPT.	(M.J.) POS. 3102	PART NAME CLIP L.H.	CHG. NC
							TOOL TARG. 100/4		
							MODEL DC9	SEC. 4110	ORIG LOC C1
							MOD CODE B	PART CODE FM	REL CODE R 3 CD
RE. BY & DATE		TOTAL							

DATE SPLIT	DEPT.	SPLIT BY	SPLIT QTY.	SPLIT DASH	BALANCE
TIME MFG.					

SPECIAL REMARKS

ENA PNA 5910327 REQ'D.
ENA PNA 5910327-1 REQ'D. 1
ENA PNA REQ'D.

STANDARD REMARKS

ANODIZE - FR PRIME Zone 401

PCS. OR FT.	WIDTH	LENGTH	SHORT. CUT	WEIGHED BY	TOT. QTY. FILL
STK LOC	FILLED BY—DATE	CUT BY	CULLS	CREDIT ACCOUNT	
POSTED BY	QTY. FOR PRICING	UNIT COST	UNIT	TOTAL COST	

MATERIAL: EXT. S-1858605 7075-T6
3

	DEPT.	OPERATION & EQUIP. CODE	WORK DESCRIPTION	UNIT (FEED)	ST UP (SPD)	PRODUCTION TOOLS	CHG.	QTY COMP.	STAMP	DATE
1										
2	651-18C		ORDER CONTROL							
3										
4										
5	401	194262	C/T			B/N-1 AT 1	NC			
6										
7										
8	406	132190	LOAD TWO -1 PARTS AT			ATD - B/N -1 MCM1	NC			
9			A TIME, DRILLING			D57-1-2-D				
10			PLANE VIEW ONE PART,			D55-.7500-5+7/8				
11			AND LEFT HAND VIEW			-8 7/8+7/8- 2 M.T.				
12			SECOND PART			D51-.1719-1 7/8+1/4				
13			S·DRILL, DRILL ALL HOLES			-3+1/4				
14			PER, B/P.			D 55-.1990-2 3/16+1/4				
15						3 7/8+1/4				
16			—SEE PG'S. 3, 4 AND 5 —							
17										
18			— END OF TAPE —							
19										
20			REVERSE POSITIONS OF							
21			TWO PARTS AND							
22			REPEAT TAPE							
23			CYCLE							
24										
25										
26										
27										
28										

PART NO.

JI. & CD. PER B/P

ED.	PLANNER & DATE	APPR. & DATE	EFFECTIVITY	REASON	TOOLING TOOLS / STAND BY TOOLS / AND OR MLO SHEET	CHG.
1	EADS	7-22-4	1 AND SUBS	1ST REL. PDR 4295 .STEVENS 7/11/4	B/N MLO	

PAGE 1 OF 5

Handout Sheet No. 5-1 (Continued)

FABRICATION OUTLINE ADDITIONAL PAGE

SECTION
MODEL
EDITION
PART NO.

LI	DEPT.	OPERATION & EQUIP. CODE	WORK DESCRIPTION	UNIT (FEED)	ST. UP (SPD)	PRODUCTION TOOLS	CHG.	QTY COMP.	STAMP	DATE
3	406		WET BARREL FIN.							
4										
5										
6	280		HARDNESS							
7										
8										
9			INSP.							
10										
11										
12	651-186		REL. TOOL							
13										
14										
15	406		PROT. PER. DPS. 3.317							
16										
17										
18	402		A 482							
19										
20										
21			223							
22										
23										
24	280		INSP. FIN. AND IDENT.							
25										
26										
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										
37										
38										
39										
40										
41										
42										
43										
44										
45										
46										
47										
48										
49										
50										
51										
52										
53										
54										
55										
56										
57										
58										

PART NO.

PAGE

Handout Sheet No. 5-1 (Continued)

PROGRAM SHEET

PAGE 1 OF 3

CHANGE		DATE
NC	T/1	7/21/64

SECTION

MODEL

EDITION

PART NO.

HOLE NO.	n	g	"X" COORD.	"Y" COORD.	"Z" COORD.	"Q" COORD.	"r"	f	s	t	m	INSTRUCTIONS
	n000										m03	
1	n001	g81	X-1038	Y 563	Z-183		r	f06	s31	t01	m07	CENTER DRILL #1, POS #1 .199/.202 DIA. (3) HOLES
2	n002			Y 1313								#2 POS #1
3	n003		X-1788									#3 POS #1
	n004	g90					r 2000					NEW "r" PT. TO CLEAR STD. LEG
4	n005		X 1625	Y 1157			r					CENTER DRILL #4, POS #2 .166/.180 DIA. 3 HOLES & (1) .750 HOLE
5	n006			Y 2657								#5 POS. #2.
6	n007		X 625	Y 1907								#6 POS #2
7	n008		X 1250									#7 POS #2
7	n009				Z 2762		r 3187	f10	s28	t02		DRILL .750 DIA. (1) HOLE POS #2
6	n010		X 625		Z-260		r	f10	s31	t03		DRILL .166/.180 DIA. (3) HOLES #6 POS #2
5	n011		X 1625	Y 2657								#5 POS #2
4	n012			Y 1157								#4 POS #2
3	n013		X-1788	Y 1313						t04		DRILL .199/.202 DIA (3) HOLES #3 POS #1
2	n014		X-1038									#2 POS #1
1	n015			Y 563								#1 POS #1
	n016										m30	END OF TAPE

PAGE

NO.

Handout Sheet No. 5-1 (Continued)

FABRICATION OUTLINE ADDITIONAL PAGE

PERISHABLE TOOL SHEET - PG. 2 OF 3

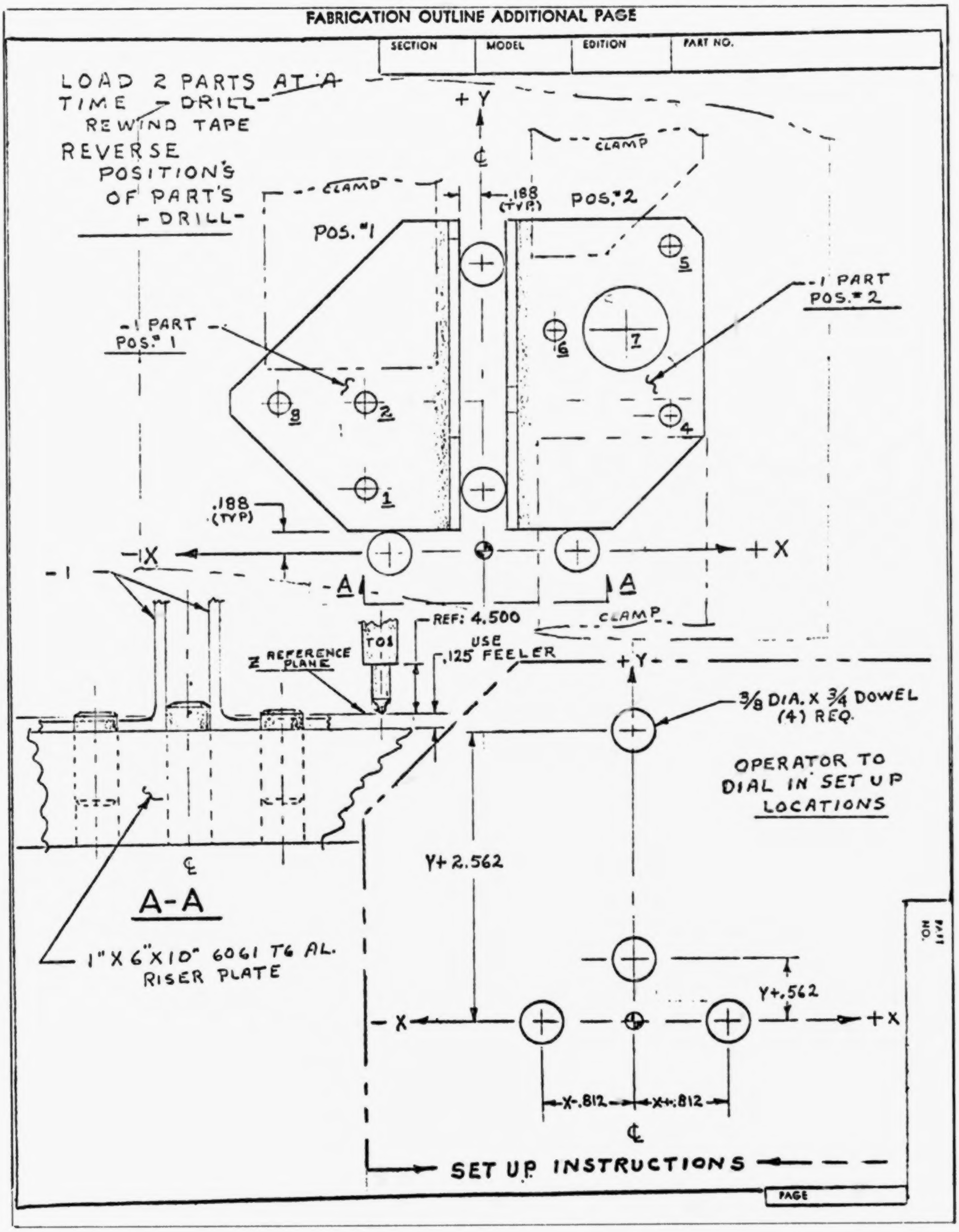
SECTION	MODEL	EDITION	PART NO.
		+	

TURRET NO.	TOOL DISCRIPTION	BASIC	MASTER COLLET	BUSHING	SET	REMASKS
T01	D57-1-2-D	S.J. 58278	S.J. 58494	#300 ERICKSON DRILL EXT.	E=4.500	CENTER DRILL (7) PLCS.
T02	D55-.7500-(5+7/8)-(8 7/8+7/8) #2 M.T.	S.J. 17299	—	—	E=7.687	DRILL .750 DIA. (1) HOLE
T03	D51-.1719 DIA.-(1 7/8+1/4)-(3+1/4)	S.J. 58278	S.J. 58503	S.J. 59234	E=4.500	DRILL .166/.180 DIA. (3) HOLES (USE 2½ SPACER)
T04	D55-.1990 DIA.-(2 3/16+1/4)-(3 7/8+1/4)	S.J. 58278	S.J. 58503	S.J. 59243	E=4.500	DRILL .199/.202 DIA. (3) HOLES (USE 2" SPACER)

PAGE

PART NO.

Handout Sheet No. 5-1 (Continued)



FABRICATION OUTLINE ADDITIONAL PAGE

LOAD 2 PARTS AT A TIME - DRILL - REWIND TAPE REVERSE POSITIONS OF PARTS + DRILL -

OPERATOR TO DIAL IN SET UP LOCATIONS

SET UP INSTRUCTIONS

SECTION
MODEL
EDITION
PART NO.
+Y
℄
CLAMP
.188 (TYP)
POS. #1
POS. #2
-1 PART POS. #1
-1 PART POS. #2
1
2
3
4
5
6
7
.188 (TYP)
-X
+X
A
A
-1
TO1
REF: 4.500
USE .125 FEELER
Z REFERENCE PLANE
3/8 DIA. X 3/4 DOWEL (4) REQ.
Y+ 2.562
Y+.562
X-.812
X+.812
℄
A-A
1" X 6" X 10" 6061 T6 AL. RISER PLATE
PART NO.
PAGE

Handout Sheet No. 5-2

A TYPICAL SET OF OPERATOR'S MANUAL INSTRUCTIONS

1. Turn switch on control console to ON. Approximately 1 min. warmup time will elapse before control will start up.
2. Start hydraulic power unit and push spindle motor START button. If spindle motor does not start, push UP and RAPID buttons on console to raise machine slide to top of stroke. Start spindle motor.
3. Note: Positioning table will not move in DIAL mode, nor with JOG buttons, unless turret is at top of stroke. Only in TAPE mode (and only if the "Position with Spindle Partially Retracted" or "Mill Modification" features have been incorporated into the machine) will the table position with turret away from top of stroke.
4. Place holding device on table and lock in position, using keyway in table and locator in X axis to position it correctly. Or push holding device into a corner stop arrangement on the subplate.
5. Dial in reference dimension for fixture location and push CYCLE START button. This will position the table properly.
6. Check fixture location with indicator. If not correct, dial in the correction with zeroing dials X and Y. It should take not more than 15 minutes to mount and locate a fixture properly.
7. Mount tools in turret as specified on Program Sheet.
8. Set spindle feeds and speeds on control station as specified.
9. Set depth, rapid approach, and rapid return for each spindle. This should take no more than 3-5 min. per spindle.
10. Place tape in reader and turn reader ON. Caution. If tape is incorrectly mounted in reader, reading error light will show on console, and machine operation will be prevented.
11. Put TAPE-MANUAL-DIAL switch on TAPE.
12. Press CYCLE START button and make chips.
13. Tape should be looped so that it does not require reinsertion in reader at end of cycle.
    Important. To join tape, make overlap with the top portion pointing in direction opposite from tape feed to prevent hooking. Overlap ends approximately 1 inch and match the tape feed holes. Use a rubberized glue, such as Elmer's, to join the ends. Too much overlap will make tape inflexible and cause reading error in tape reader and stoppage of machine.
14. To stop machine while in tape operation, in order to check an operation or to add another operation by dials, use one of the following procedures:

Method I

a. Turn TAPE-MANUAL-DIAL switch to MANUAL.

b. Bring slide to top of stroke.

c. Turn reader knob counterclockwise to back up tape one command block, since reader has read and stored the next group of instructions and would bypass the operation being checked. If the hole is completed, move back one command block. If you wish to repeat the operation being checked, move tape back two command blocks. A command block is recognized by means of the hole punched by the carriage-return key on the typewriter in the 8th channel on the tape.

Method II

a. Push CYCLE STOP during the operation previous to the one it is desired to check.

b. If the reader is reading, it will finish reading that block and stop. The machine will perform the last command read, which will be the operation it is desired to check. Thus, one operation at a time may be performed by alternately pushing CYCLE START and CYCLE STOP.

unit 6

FEED, SPEED, AND HORSEPOWER

PLAN OF INSTRUCTION

Objectives

- To review with the student the necessity for the elimination of guesswork in machine operation and the means of accomplishing it
- To acquaint the student with factors peculiar to N/C that affect the selection of feeds and speeds

Introduction

1. Define speed and feed.
2. Demonstrate the effect of variables on tool life, dimensional accuracy, and part finish.

Presentation

1. Illustrate the variables that affect determination of cutting speed and tool life expectancy.
2. Explain the derivation of the formulas in the resource unit.
3. Illustrate the use of nomographs and slide calculators in the determination of variables.
4. Relate chip thickness to horsepower requirements, volume of metal removed, and finish.
5. Provide student practice to develop proficiency in the calculations involved in machining.
6. Discuss research and development in the areas of machine tool productivity and metal removal.
7. Elaborate on N/C feed and speed programming.
8. Discuss problems of dwell, overshoot, and feed rate overrides on contouring systems.
9. Describe notations and codes for speed and feed, and the procedures for special cases, such as tapping.

RESOURCE UNIT

Cutting speeds and feeds are the machining factors most directly related to the primary machining operation--the removal of chips. Yet in this era of increasing precision, the fundamentals of speed and feed are not often taught in terms of modern capabilities and usually are not even properly defined.

Speed and Feed Defined

Speed is defined as distance per unit of time. The familiar miles per hour (mph), feet per minute (fpm), and inches per minute (ipm) are all designations of speed. But revolutions per minute (rpm) does not express a speed, because revolutions do not indicate a linear distance. In machine tool usage it is better to consider rpm as merely expressing an angular rate. A revolution is once around--but around what? When a workpiece is turned at a constant angular rate, the circumference is reduced as the cut is made, and the cutting speed changes in accordance with the method of tool feed.

The cutter feeds into the work at a rate usually expressed in inches per minute or thousandths per minute. But many machine tools give the settings in thousandths of an inch per revolution, probably because of the mechanical linkage involved. The revolution is not a unit of time, although in a given case it can be made equivalent to a unit of time by calculation. The need for the calculation, and the distinctions, should be kept clearly in mind.

Allowances for Variables

The best results in machining generally are obtained when the equipment is not overloaded. This is particularly true with N/C equipment, where the control system may be sensitive to voltage fluctuations caused by the loading and where loss of control due to overload shuts off the machine, with resulting errors in cutter path development and part geometry. Tool life, too, can be drastically shortened by breakage when tools are overloaded. Another cause of loss is the use of cutting speeds above the correct limits for the material and the tool in use. And the incorrect selection of speeds and feeds directly contributes to poor part finish, as well as to dimensional inaccuracy. The production of specified finish on exotic materials is of critical concern and is difficult if correct chip-producing relationships are not maintained.

In any process the actual production of the chip requires that a maximum number of the variables be considered. These variables can be classified in three groups: machine variables, work variables, and tool variables. All are directly interrelated, and all affect the efficiency, accuracy, and indeed the possibility of machine tool utilization.

With respect to the machine tool, first consideration is given to its physical dimensions and horsepower. In addition, its original capabilities, age, mechanical condition, and tooling relationships must be evaluated. Holding devices, which can greatly extend the capabilities of the machine, come in a greater variety than the machine tools do. The rigidity and repeatability of the holding fixtures are of particular importance. Other machine variables include the available rate settings for spindle and table travel and the types of cutting fluids that can be used. N/C machines have, as well, a wide variety of control system variables affecting their capabilities.

Work variables include the chemical and mechanical characteristics of the material, the physical dimensions (shape, size, and weight), and the amount of material to be removed. Pieces of material that seem identical can in fact have vastly different characteristics, obtained by an endless variety of possible heat and cold treatments that affect machinability and therefore influence the efficiency and accuracy that can be maintained. Mechanical properties and microstructure of materials can be determined. The machinist must understand the nature and effects of each of these variable factors; among them hardness, ductility, tensile strength, and shear strength.

Tool variables include material, geometry, holders, and the amount of work contact. Common tool materials include high-speed steels with a wide range of capabilities, sintered carbides, and ceramic materials. The latter are used on engine lathes and in other applications where there is continuous tool contact. Each of these tool materials has a definite range of cutting speeds related to the material being cut. The geometry of the tool, including rake angles, length, overhang, rigidity, size, and number of cutting surfaces, must be considered in relation to the depth of cut, kind of holders, and the physical dimensions of the part.

Calculations

It is both essential and possible to remove some of the guesswork from the analysis of the variables. The programming function is taking over from the operator the task of specifying feeds and speeds. To support programming, two kinds of research and development are in progress:

- Machine tool builders are working out adaptive controls whereby the machine tool will be able to sense and make needed corrections to programmed speeds and feeds.
- Research is in progress seeking a method that will enable computers, supplied with experimental data, to select correct speeds when information is furnished that includes material, cutter, depth of cut, available horsepower, tolerance, finish, and other pertinent items.

Success in these endeavors will minimize the human factor in speed and feed selection.

However, tool designer, programmer, and operator will still need an understanding of the mathematical determination of correct speeds and feeds.

Independent determinations of these quantities will be required for tape proving, at times of machine malfunction, and when variations in dimensions or finish occur. The designer, programmer, and operator should know the formulas for these calculations.

RPM. The rpm formula is found in several forms, of which the simplest is

$$\text{rpm} = \frac{4\ CS}{D}$$

where CS is circumferential speed (speed at the periphery of the work) in feet per minute and D is the diameter in inches. The constant 4 is an approximation of $12/\pi$, derived from the conversion of feet to inches and of circumference to diameter. More exact formulas are available but are not generally required because of the limited number of rate settings usually available on a machine tool. The general rule is to calculate rpm, using the "high normal" fpm for the material and cutting tool being used, and then select the next lower rpm setting available on the machine. In conventional machining, corrections could be made upon evaluating the results. With N/C, production of a new control tape is necessary unless the operator has mechanical control of the rate settings. Few N/C machine controls provide rpm overrides.

IPM. The ipm or feed formula is usually given as

$$\text{ipm} = \text{rpm} \times CL \times T$$

where rpm is that used on the machine (not that calculated), CL is the chip thickness (chip load) in thousandths, and T is the number of cutter teeth. For a given ipm, any change in rpm will affect the chip thickness. This formula gives an optimum cutting relationship, but considerations of finish or tool life may require modification of the calculated amount. Also, reduction in chip load is essential when long cutters or cutters with small diameter or excessive overhang are used. Table travel speeds must be reduced when cutter paths involve cornering or reversing. When the proper feed for an N/C machine is to be determined, additional factors must be considered in the interests of cutter life and of the dimensional stability of the part being produced. These factors include problems arising from dwell and overshoot, especially important because of the tendency of many materials to work-harden. Feedrate overrides are sometimes provided, under operator control, but they are poor substitutes for correct specification of feed rates in the original program.

Material Removed. Determination of the correct amount of material to remove at each cutter pass involves consideration of the width and depth of cut, machinability of the material, feedrate, and available horsepower (hp). The relation used is

$$\text{hp} = \frac{d \times W \times F}{K}$$

where d is the depth of cut and W the width of cut, both in thousandths. The symbol F is feed in inches per minute, and K is a constant related to the material characteristics, taken from tables similar to the following:

Material	K
Aluminum	2.25
Brass	2.00
Cast Iron	1.00
Soft Steel	0.85
Hard Steel	0.50

If the machine horsepower is known and the feed is determined from the formula given previously, then either d or W can be arbitrarily determined and the other calculated from the formula given here.

Tapping Feeds. Tapping feeds are determined using this formula:

$$F = \frac{\text{Spindle rpm}}{\text{Threads per in.}}$$

When the exact feed rate is not available, the next lower setting on the machine is used.

Machine Efficiency. The following formula is sometimes useful:

$$\text{Efficiency (\%)} = \frac{\text{Machine hp} \times 100}{\text{Needed}}$$

Cut Time. To determine the time required to make a cut, the following formula is used:

$$\text{Cut Time} = \frac{L \times N}{F}$$

where L is length of cut in inches, N is the number of cuts, and F is feed in inches per minute. To determine a standard cutting time, the approach time and the time required for the cutter to clear the work must be added.

Simplified Methods of Estimation

Most of the foregoing formulas, and other formulas involved in the calculation of machining variables, have been made available as tables, nomographs, and special slide calculators. These can often be found in the handbooks or advertising materials of machine tool builders. With the formulas in this unit memorized, a programmer can use any standard calculator or simple slide rule to determine the values fast and easily. Many N/C programmers keep at hand complete tables that can be quickly checked for values involving any of the variables. All of the foregoing are satisfactory for operating use.

Factors Peculiar to N/C

Successful research and development have brought many improvements in machine tool productivity, cutter design, and tool use. Techniques have been devised to remove ever-smaller chips, including removal of chips of molecular size by electrical discharge and chemical milling. In contrast, development of rolling techniques similar to knurling and thread rolling has resulted in the ability to produce chips as large as a man's hand. N/C may eventually be used to control both these extremes, but today and in the near future N/C will be applied principally to improve the productive capability of more conventional chip removal methods.

Increased productivity resulting from more nearly continuous machine use has justified the adoption of N/C. To realize its potential, the input to the control tape must be refined to a degree that many conventional machine operators do not consider possible. To achieve this, programmers must know the correct speeds and feeds to be used and must understand fully the dangers of cutter dwell. They must understand and use the correct procedures and sequences to avoid overshoot as the table speed is decelerated for cornering or for other changes in motion.

The complexity of programming rapid travel is increased by the need to designate correct directions and rates for both acceleration and deceleration, as well as by the presence of clamps that must be avoided. Failure to accomplish this will increase operation time, reduce cutter life, and reduce efficiency. Special codes and notations for designating feeds and speeds are found in the programmers' manuals for the various systems. The U.S. Air Force at one time specified, for certain procurements, a more general form of control notation. This notation, known as the "Magic 3" system, was explained in NAS Bulletin 955.

The selection of speeds and feeds is not normally the task of the N/C machine operator. Where the operator's instruction sheet calls out manual settings, he makes them. And at tape proving time an occasional use of feed override is noted, which the next operator makes per instruction. When the tape has been altered in any way since it was last used, the operator should be alert to all speed and feed settings. During tape proving, the operator may well recalculate all rpm settings, make a quick check of feed rate callouts, and carefully note all acceleration and deceleration sequences. At the present state-of-the-art, programmers are more likely to make mistakes in speeds and feeds than in the problems inherent in obtaining correct dimensional relationships.

INSTRUCTIONAL TECHNIQUES

References

Begeman, M. L., and B. H. Amstead. Manufacturing Processes (5th edition). New York: John Wiley & Sons, Inc., 1963.
Brierly, R. G., and H. J. Siekmann. Machining Principles and Cost Control. New York: McGraw-Hill Book Company, 1964.
Machinery's Handbook, Edited by H. L. Horton. (16th edition). New York: The Industrial Press, 1959.
The New American Machinist's Handbook. Edited by Rupert LeGrand. New York: McGraw-Hill Book Company, 1955.

Handout Materials

Slide calculator for speed and feed. Available from Kearney and Trecker Corp. and others
Speed, feed, and horsepower nomographs (Handout Sheet 6-1)
Tables on speed and feed, with formulas (Handout Sheet 6-2)
Test Sheets No. 602 and 603 (Handout Sheet 6-3 and 6-4)
Surface finish definition card, Brush Analyzer or other

Audio-Visual Materials

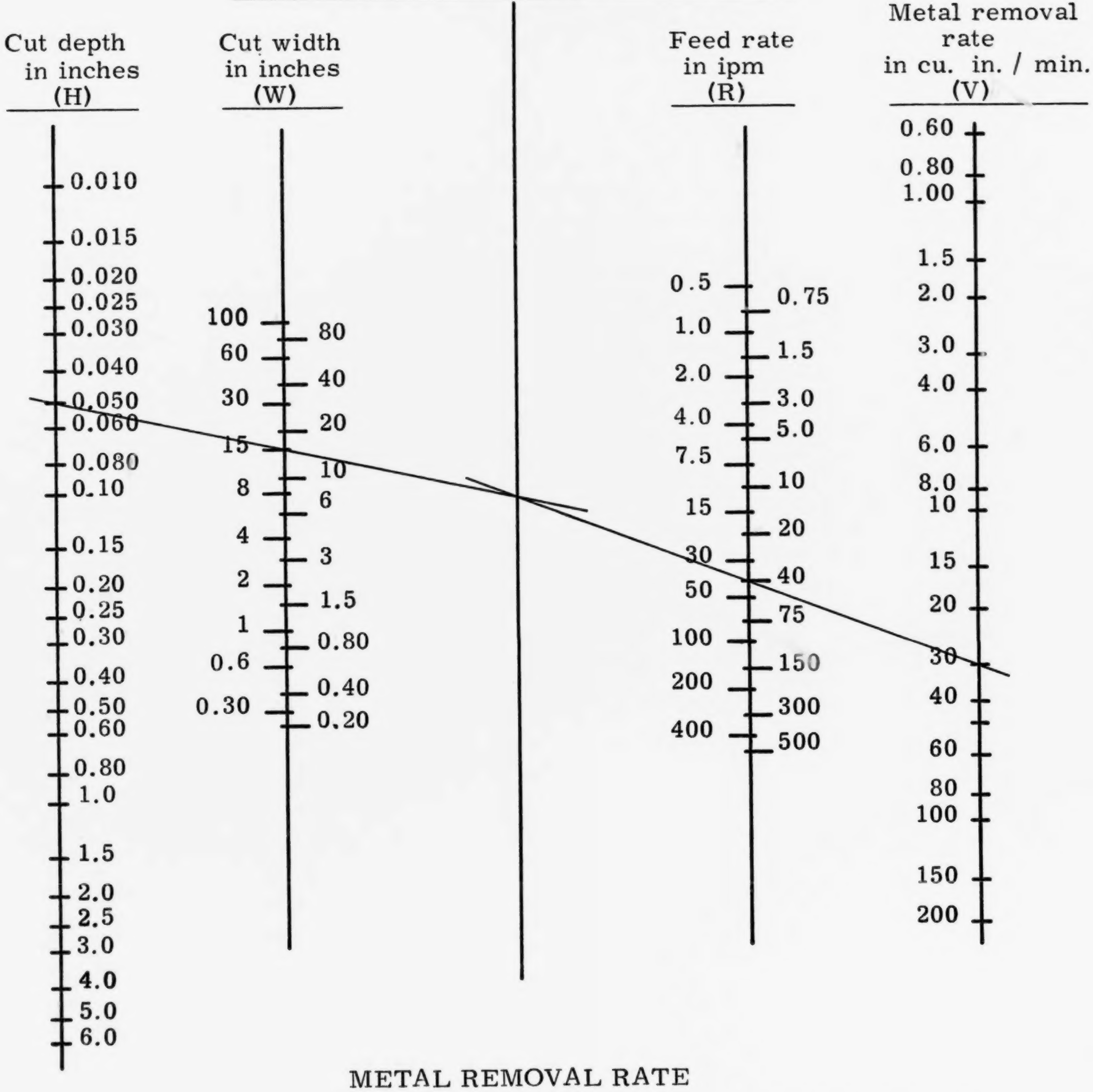
Cool Chips. Film produced by Cincinnati Milling Machine Co.
Workpiece samples made under test conditions
Programmer's Manuals for several control system/machine tool combinations

Student Activities

1. Solve sample problems from Test Sheets No. 602 and 603.
2. Identify various surface finish patterns and roughness callouts from samples.

Handout Sheet No. 6-1

MACHINE TOOL NOMOGRAPHS (p. 1 of 4)



METAL REMOVAL RATE

To find R in terms of H, W, and V, lay a straightedge along the values for H and W. From the point where the straightedge crosses the center line, run a line through the value of V. Read the answer on R. The example shows H = 0.050 in., W = 15 in., V = 30 cu. in. / min. The answer is 40 ipm.

Handout Sheet No. 6-1

MACHINE TOOL NOMOGRAPHS (continued)

SPINDLE SPEED

To find N in terms of C and D, run a line from the value of C to the value of D. Read the answer on N. In the example, C = 4000 and D = 3. The answer is N = 5000.

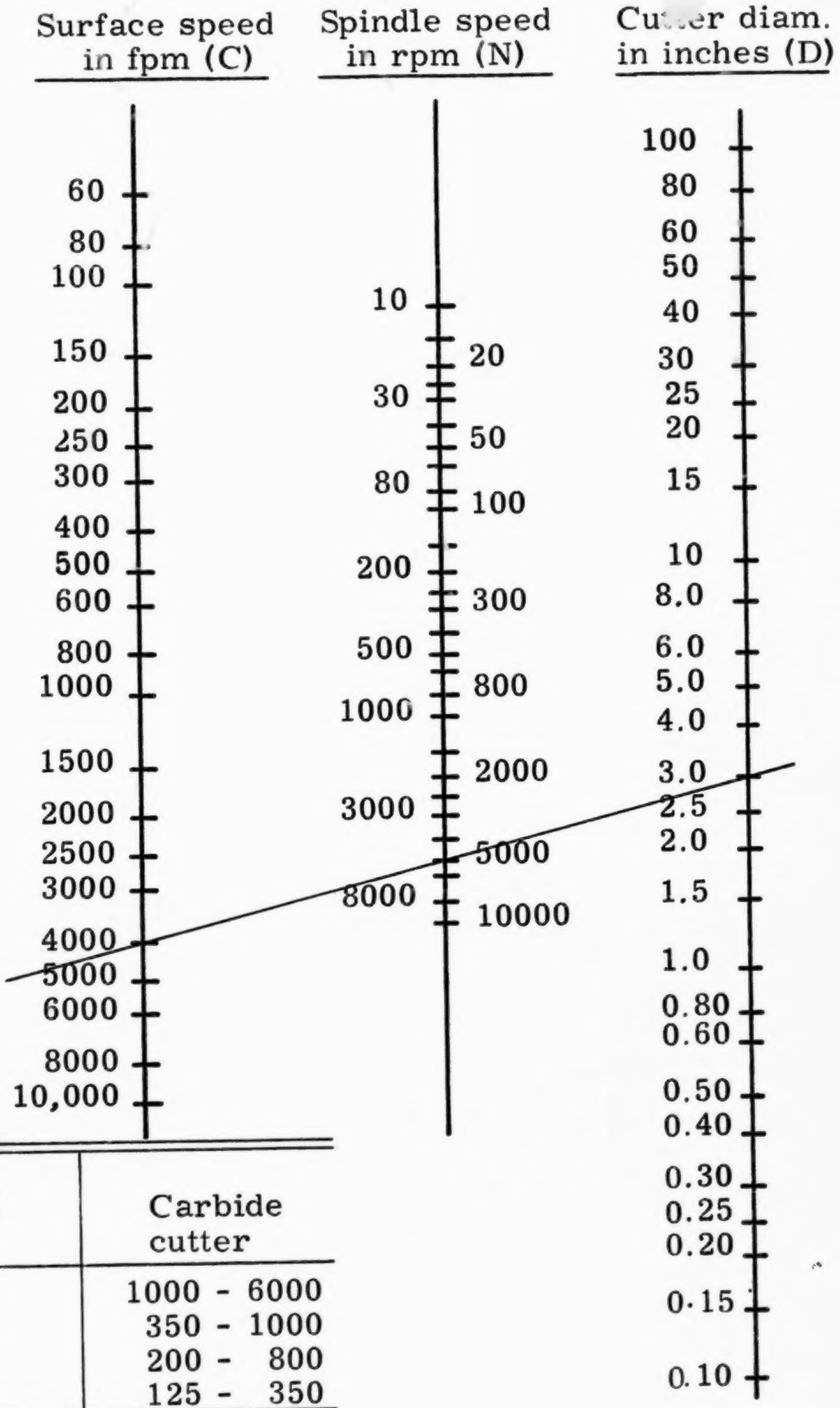
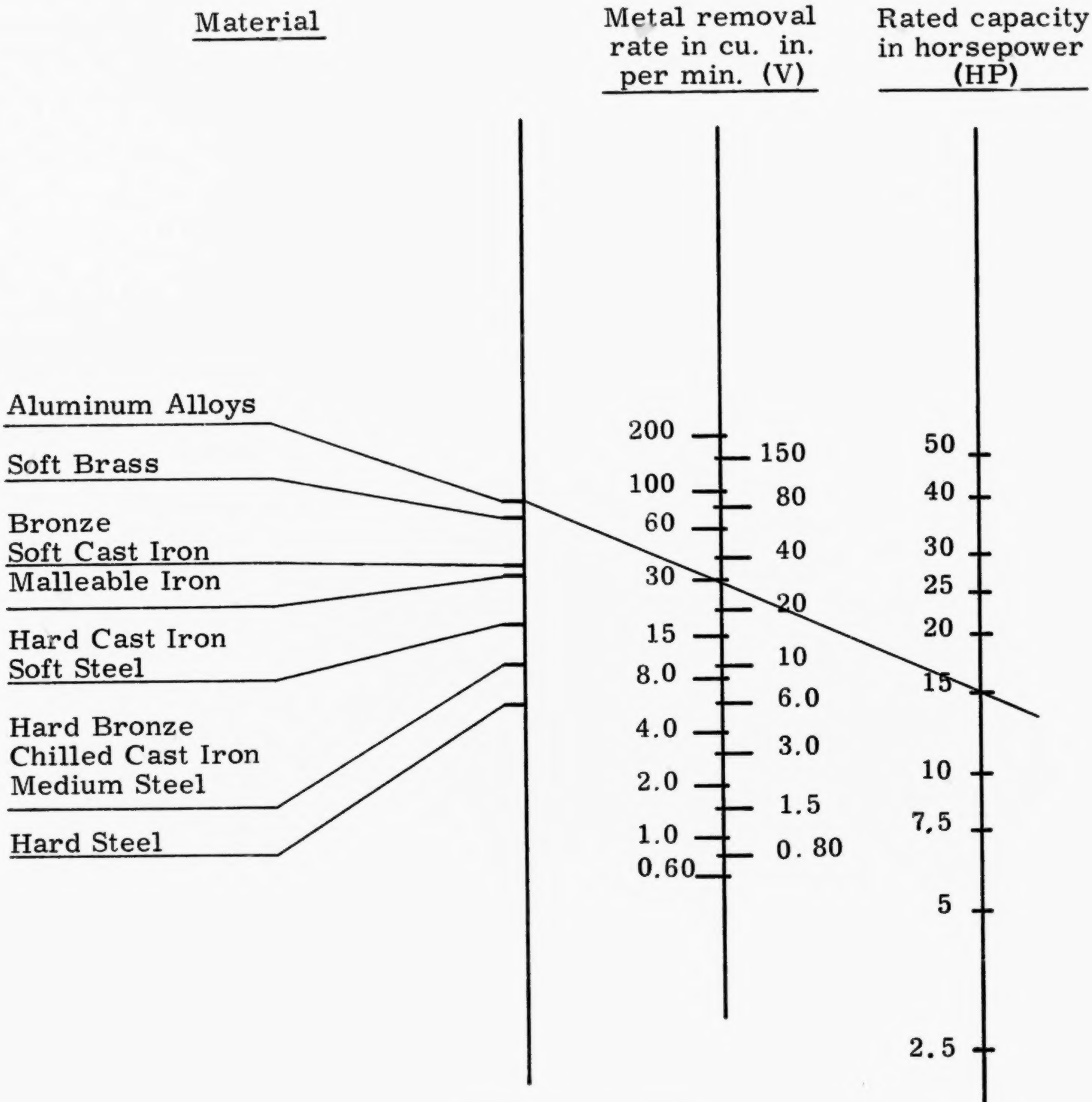

Surface speed in fpm (C)
60
80
100
150
200
250
300
400
500
600
800
1000
1500
2000
2500
3000
4000
5000
6000
8000
10,000
Spindle speed in rpm (N)
10
20
30
50
80
100
200
300
500
800
1000
2000
3000
5000
8000
10000
Cutter diam. in inches (D)
100
80
60
50
40
30
25
20
15
10
8.0
6.0
5.0
4.0
3.0
2.5
2.0
1.5
1.0
0.80
0.60
0.50
0.40
0.30
0.25
0.20
0.15
0.10

Table of Surface Speeds

Material	High speed steel	Carbide cutter
Aluminum Alloys	600 - 2000	1000 - 6000
Brass - Soft	500 - 1500	350 - 1000
Bronze	200 - 300	200 - 800
Bronze - Hard	100 - 200	125 - 350
Cast Iron - Soft	100 - 120	250 - 400
Cast Iron - Hard	70 - 100	200 - 300
Cast Iron - Chilled	50 - 60	150 - 250
Malleable Iron	100 - 120	300 - 400
Steel - Soft	100 - 180	350 - 750
Steel - Medium	80 - 120	250 - 400
Steel - Hard	30 - 50	150 - 300

Handout Sheet No. 6-1

MACHINE TOOL NOMOGRAPHS (continued)

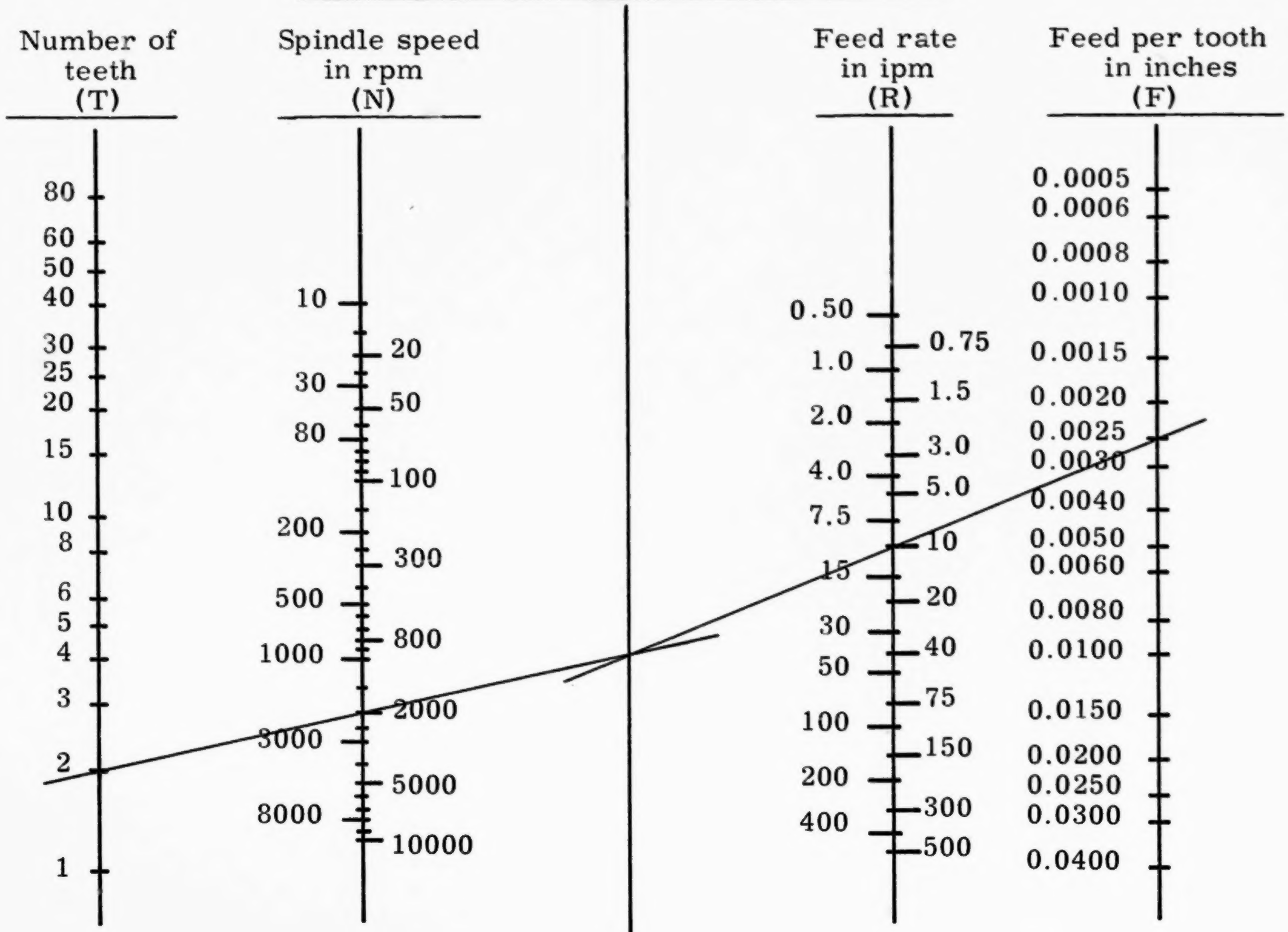

Material
Metal removal rate in cu. in. per min. (V)
Rated capacity in horsepower (HP)
Aluminum Alloys
Soft Brass
Bronze
Soft Cast Iron
Malleable Iron
Hard Cast Iron
Soft Steel
Hard Bronze
Chilled Cast Iron
Medium Steel
Hard Steel
200
150
100
80
60
40
30
20
15
10
8.0
6.0
4.0
3.0
2.0
1.5
1.0
0.80
0.60
50
40
30
25
20
15
10
7.5
5
2.5

HORSEPOWER

To find V in terms of HP and the material type, run a line from the material scale to the HP scale. Read the answer on V. In the example, the horsepower is 15 and the material is aluminum. The answer is V = 30.

Handout Sheet No. 6-1

MACHINE TOOL NOMOGRAPHS (continued)


Number of teeth (T)
80
60
50
40
30
25
20
15
10
8
6
5
4
3
2
1
Spindle speed in rpm (N)
10
20
30
50
80
100
200
300
500
800
1000
2000
3000
5000
8000
10000
Feed rate in ipm (R)
0.50
0.75
1.0
1.5
2.0
3.0
4.0
5.0
7.5
10
15
20
30
40
50
75
100
150
200
300
400
500
Feed per tooth in inches (F)
0.0005
0.0006
0.0008
0.0010
0.0015
0.0020
0.0025
0.0030
0.0040
0.0050
0.0060
0.0080
0.0100
0.0150
0.0200
0.0250
0.0300
0.0400

FEED RATE

To find R in terms of T, N, and F, lay a straightedge along the values for T & N. From the point where the straightedge crosses the center line, run a line through the value of F. Read the answer on R. The example shows T = 2, N = 2000 rpm, F = 0.0025 in. The answer is R = 10 ipm.

Feed per tooth table
(Carbide cutters*)

Aluminum Alloys	0.010 - 0.030
Soft Brass	0.010 - 0.030
Bronze	0.005 - 0.015
Hard Bronze	0.003 - 0.010
Cast Iron - Soft	0.010 - 0.030
Cast Iron - Hard	0.005 - 0.015
Cast Iron - Chilled	0.005 - 0.010
Malleable Iron	0.010 - 0.030
Steel - Soft	0.010 - 0.020
Steel - Medium	0.007 - 0.015
Steel - Hard	0.003 - 0.010

*for HSS cutters use 0.008 for steels

Handout Sheet No. 6-2

TABLES AND FORMULAS ON FEEDS AND SPEEDS

The following formulas are helpful in determining the speed and feed to use on milling machines. Formulas 1 and 2 are used with lathes when the cutting feet per minute and the feeds are known. When applied to lathes, the diameter of the work, rather than of the cutter, is used because it is the work that revolves.

The constant $0.26 = \frac{3.1416}{12}$

No. 1. To find rpm:

$$\text{rpm} = \frac{\text{fpm}}{0.26 \times D}$$

rpm - Revolutions per minute
fpm - Peripheral speed (feet per minute)
D - Cutter diameter in inches

No. 2. To find cutting feet per minute of the cutter:
$\text{fpm} = 0.26 \times D \times \text{rpm}$

No. 3. To find feed per tooth per revolution, or chip load:

$$CL = \frac{\text{ipm}}{T \times \text{rpm}}$$

CL - Chip load or chip thickness
ipm - Feed in inches per minute
T - Number of teeth

No. 4. To find the feed:
$\text{ipm} = CL \times T \times \text{rpm}$

FPM and Chip load vs. Materials and Cutters for Mills

This table should be used as a starting point or guide. Both fpm and chip load will vary with grade of material and condition of machines.

Material	High speed cutter		Carbide cutter		Stellite cutter	
	fpm	CL	fpm	CL	fpm	CL
Cast iron	75	0.010	250	0.008	120	0.009
Malleable iron	95	0.013			150	0.008
Brass	150	0.015				
Steel	60	0.006	125	0.005		

Examples

1. A cast iron face is to be machined with a 6 inch carbide cutter having 12 teeth. What would be the rpm and the feed to use?

   From the table, we take as guides 250 fpm with a CL of 0.008.
   From Formula No. 1: $\text{rpm} = \frac{250}{0.26 \times 6} = 160$
   From Formula No. 4: $\text{ipm} = 160 \times 12 \times 0.008 = 15.36$

2. Find rpm and feed to use when working cast iron with a 4 inch high-speed cutter having 8 teeth.

   From table: fpm = 75; CL = 0.010
   From Formula No. 1: $\text{rpm} = \frac{75}{0.26 \times 4} = 72$
   From Formula No. 4: $\text{ipm} = 72 \times 8 \times 0.010 = 5.76$

3. A job is running at 104 rpm with a 6-inch cutter. What is the fpm?

   From Formula No. 2: $\text{fpm} = 0.26 \times 6 \times 104 = 162$

Handout Sheet No. 6-3

TEST NO. 602

Listed below each numbered item are four possible answers. Decide which of the four is correct, or most nearly correct; then write the corresponding letter (A, B, C, or D) in the blank space to the right of that item.

1. A gear blank with 6 inch diameter is to be turned at 62 fpm. The correct rpm setting will be:
   A. 32 B. 41 C. 54 D. 69 1. __________

2. A standard-length end mill cutter of 2 inch diameter is to be set for milling aluminum at 4200 fpm. The correct rpm setting will be:
   A. 8250 B. 7800 C. 5400 D. 3500 2. __________

3. A milling cutter with 7-1/2 inch diameter should be set at which rpm setting to cut at 50 fpm?
   A. 100 B. 75 C. 50 D. 25 3. __________

4. A #7 drill is to cut tool steel at 45 fpm; the correct rpm setting is:
   A. 650 B. 750 C. 825 D. 975 4. __________

5. Using the 2/3 reduction factor for reamers, what will the correct rpm setting be for a 3/16 inch diameter reamer cutting steel that has a machinability of 95 fpm?
   A. 3500 B. 2400 C. 1200 D. 1000 5. __________

6. What feed rate setting would be used on the engine lathe of problem 1 above if the specified CL was 0.005?
   A. 0.010 B. 0.4 C. 0.005 D. 0.2 6. __________

7. The mill cutter of problem 2 above has 6 flutes. How many minutes will be required to mill a part 18 inches long if the CL used is 0.002?
   A. 5 B. 1.5 C. 0.9 D. 0.2 7. __________

8. The milling cutter of problem 3 above has 13 teeth. For each tooth to have a chip load of 0.009, the ipm setting would be:
   A. 2.9 B. 3.4 C. 6.2 D. 11.0 8. __________

9. The drill in problem 4 must drill 40 holes, each 0.950 inch deep. If a CL of 0.0025 is used, the total drilling time in minutes will be:
A. 5 B. 10 C. 19 D. 25

9. ____________

10. The 4-flute reamer used in problem 5 is to be used to finish-ream 25 parts, each having a reamed hole 4 inches long. How many minutes cutting time will be saved if a CL of 0.010 is used rather a CL of 0.0065?
A. 0.50 B. 1.14 C. 2.17 D. 2.82

10. ____________

Handout Sheet No. 6-4

TEST NO. 603

Listed below each numbered item are four possible answers. Decide which of the four is correct, or most nearly correct; then write the corresponding letter (A, B, C, or D) in the blank space to the right of that item.

1. To turn a piece of stock having an outside diameter of 7/8 inch at a speed of 95 fpm, the rpm setting is: 1. ________
   A. 205 B. 290 C. 360 D. 410

2. If the part in problem 1 is 12 inches long, and 5 minutes are required to reverse the part to turn both ends, what will be the total time in minutes required to handle the part if a CL of 0.003 is used? 2. ________
   A. 12.1 B. 14.6 C. 16.2 D. 18.9

3. How many minutes will be saved on an order for 25 of the parts in problem 2 if the chip load is increased to 0.007? 3. ________
   A. 139 B. 160 C. 191 D. 262

4. A side mill cutter with 4-1/2 inch diameter is to be operated at 160 fpm. The correct rpm setting is: 4. ________
   A. 60 B. 95 C. 135 D. 170

5. When cutter travel on the 26-tooth cutter of problem 4 is 7 inches per part and there are 250 parts on order, what is the machining time in hours with chip load set at 0.004? 5. ________
   A. 2 B. 1.75 C. 1.5 D. 1.35

6. If the speed required of a letter W drill is 45 fpm, the rpm setting should be: 6. ________
   A. 260 B. 310 C. 450 D. 600

7. A 4-flute end mill cutter, 3/4 inch diameter, is running at what speed if the rate setting is 450 rpm? 7. ________
   A. 60 fpm B. 85 fpm C. 60 rpm D. 85 rpm

8. In problem 7, with a CL of 0.014 what is the speed of the feed? 8. ________
   A. 25 ipm C. 0.056 per rev.
   B. 0.010 per rev. D. 12 ipm

9. A shell end mill, 1-1/2 inches in diameter with 8 teeth, is to run at 70 fpm with a CL of 0.0035. The correct speed of the feed is:
A. 4.65 B. 2.2 C. 0.028 D. 0.014

9. __________

10. In the setup of problem 9 the feed rate is increased to 0.038 per revolution. On a part 8 inches long, how much faster (in minutes) will the machining time be?
A. 1.0 B. 0.75 C. 0.58 D. 0.46

10. __________

unit 7
COORDINATE DEFINITION OF PART GEOMETRY

PLAN OF INSTRUCTION

Objectives

- To relate the usual trade mathematics of the machinist to the mathematical definition of dimensional relationships
- To make the student aware of the mathematics required for the functional utilization of N/C
- To develop the student's understanding of the Cartesian coordinate system as it is applied to machine tool axes and motions
- To introduce to the student the techniques of defining geometric relationships in space

Introduction

1. Explain the methods used in jig borer setup and operation.
2. Illustrate similar concepts in the construction and use of road maps.
3. Diagram the Cartesian coordinate system.

Presentation

1. Elaborate on the application of Cartesian coordinates to machine tool axes.
2. Develop the geometric methods of describing points, lines, and circles.
3. Illustrate the use of geometry and trigonometry in layout.
4. Relate layout techniques to N/C motion definition.
5. Demonstrate the use of mathematics to determine point locations for N/C programming.
6. Provide student exercise in mathematical calculation and definition of points.
7. Assign home study exercises in geometrical definition and determination of point and surface location.

RESOURCE UNIT

Mathematics is an accepted tool of the machinist and of the tool and die maker. These artisans are chiefly interested in mathematics as it relates to the determination of dimensions and of the correct feeds and speeds for conventional equipment. But mathematics is even more important in the programming and operation of N/C equipment. In the early development of N/C by the Parsons Corp., the necessity for mathematical assistance by a computer to establish the coordinate dimensions of points along a cutter path emphasized this importance.

Jig Borer Dimensioning

Only recently jig borer operators have started to use desk calculators to assist in the required mathematical determinations. Indeed, many plants have not yet taken advantage of the significant time savings that can be realized by the use of calculators. It is still considered good practice for the jig borer operator to convert the blueprint dimensions to the coordinate form essential for jig borer setup. Knowledge of geometry and trigonometry is vital to the correct specification of hole centers and of the other dimensional relationships of the work.

The jig borer technique is often applied to less demanding operations, such as vertical milling. And the capabilities of such dimensioning have been developed to the point that the use of rotary tables and other indexing mechanisms is declining in most tool shops. Numerical control of machine tools depends primarily on the use of coordinate dimensions, which permit adaptation of many classes of work from conventional to N/C equipment.

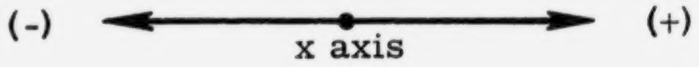
For those not familiar with specific machining techniques such as those of the jig borer, an analogy can be made with the construction and use of maps. Mapmakers use Cartesian coordinates in many applications. Points on a map are described, with reference to a designated point of origin, in terms of north, south, east, and west. Direction and distance can be specified quickly and accurately; distance and direction can be computed if latitude and longitude are known, and vice versa.

The same Cartesian coordinate system is used in machine control because of its compatibility with and usage in all branches of science. Cartesian coordinates satisfy the requirement for a method of callout of machine tool motions which is readily recognized and understood.

Machine Axis Designation

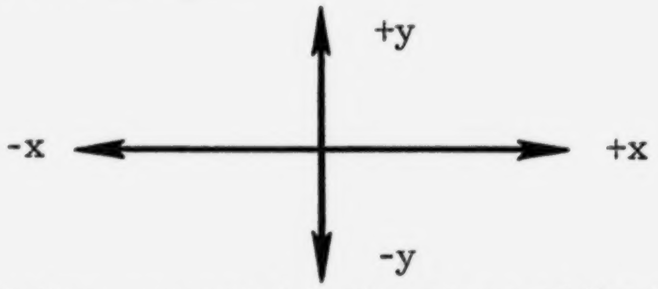
If a machine is to be controlled by numerical input, a numerical system is necessary to define locations and motions. For this purpose, Cartesian coordinates are related to machine tool actions, and digital information is developed which defines the required locations and motions.

If a given point is specified as the starting point or origin, a line drawn through that point can be designated the "x" axis.

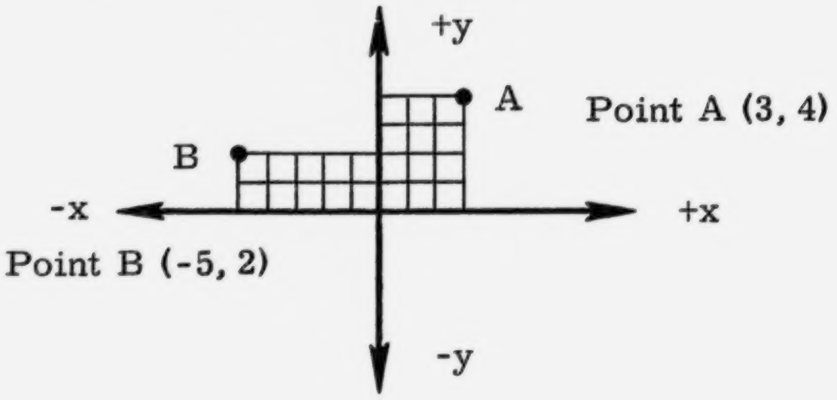


Starting at the origin and moving to the right is considered moving in a plus (+) direction; to the left in a minus (-) direction.

By drawing another line through the origin at right angles to the first, another axis (the "y" axis) is established. Along the y axis, movement from the origin upward is plus, downward is minus.



It is then possible to define any point in the plane of the two axes by simply stating the distance and direction it lies from the origin in terms of movement parallel to the x and y axes. Thus, point A in the accompanying sketch is 3 units in a +x direction and 4 units in a +y direction from the origin.



Point B is 5 units in a -x direction and 2 units in a +y direction. Motion may also be described; moving from point A to point B is motion in an -x-y direction.

The linear axes of such a system are usually called x, y, and z. The x axis is related to the machine tool as the direction of the longest movement of the machine table; the y axis is usually assigned to the plane of the table (for example, as the horizontal cross slide motion). The third axis, z, is perpendicular to the xy plane and is usually assigned to the spindle feed motion. Systems called 2D systems designate motion in the xy plane. The 3D or 3-axis systems involve, in addition, control of the z axis, as in depth of cut.

When these relationships are established, it is relatively simple for a programmer to cause the machine to move from one point to another. And application of the principles of analytic geometry enables the programmer to determine cutter locations and part geometry that are not always obvious from the part drawing.

Four-axis and five-axis machines use rotary or angular motions of the xy plane and the z axis to make it possible to develop more complex mold lines, as in continuous path contouring. A higher order of mathematics is required, emphasizing spatial relationships, and the calculations may be performed by the use of computer routines previously established.

Fig. 7-1 illustrates the application of x, y, and z axes in a machine tool configuration. Other examples are given in the handout sheets at the end of this unit, which have been adapted from National Aerospace Standards (NAS 938) of the AIA.

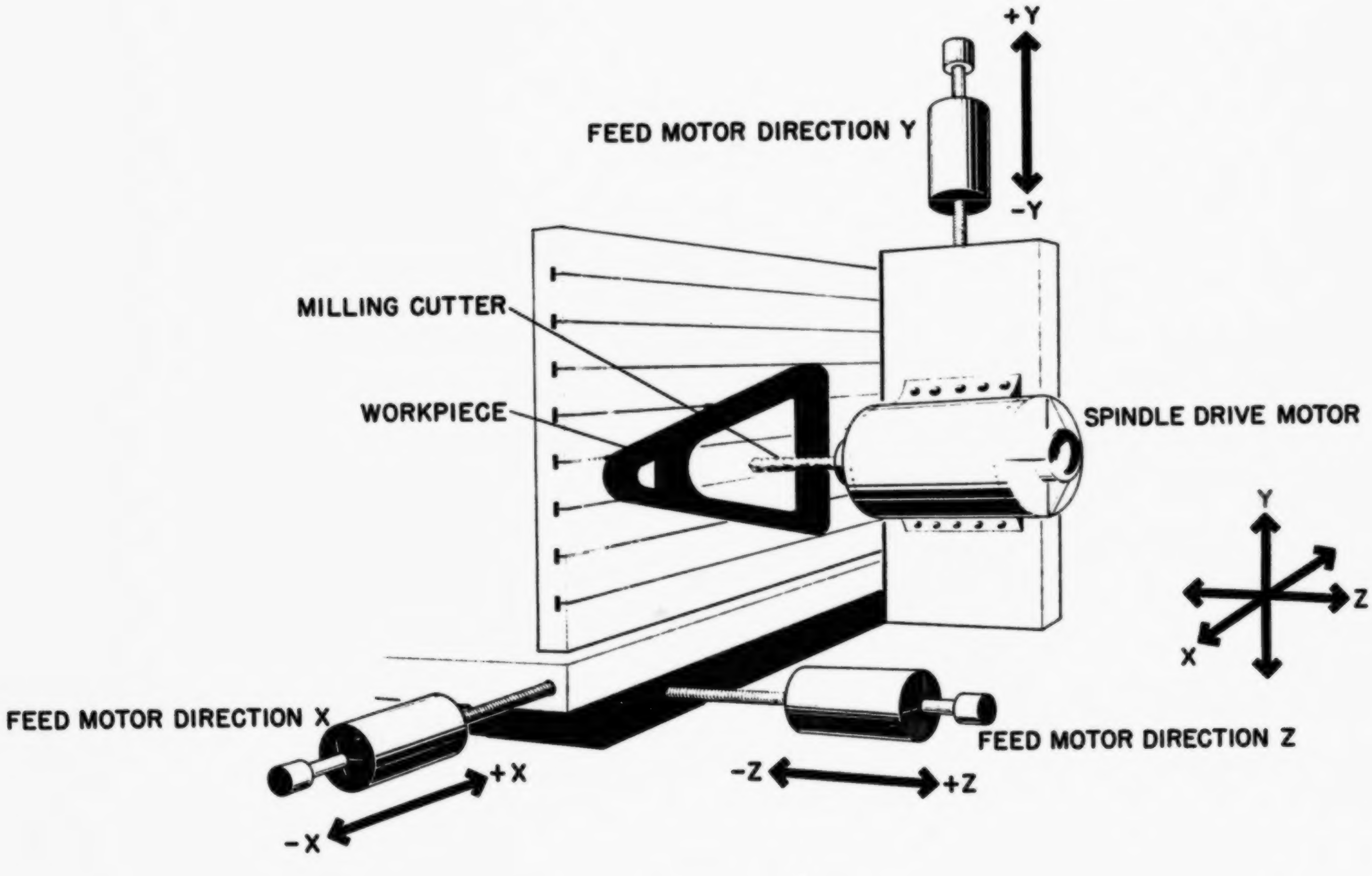

+Y
FEED MOTOR DIRECTION Y
-Y
MILLING CUTTER
WORKPIECE
SPINDLE DRIVE MOTOR
Y
Z
X
FEED MOTOR DIRECTION X
+X
-X
-Z
+Z
FEED MOTOR DIRECTION Z

Fig. 7—1. Machine axis designation

Geometric Definitions

Programming languages give the programmer many options to enable him to make up a control program in the most efficient way possible. The various ways in which the basic elements of shop layout--points, lines, and circles--may be defined illustrate this flexibility. Programming language, of course, also includes geometric definitions for complex figures, such as parabolas, ellipses, cylinders, and the like.

A point can be defined by any of the following:

- Coordinates
- The intersection of two lines
- The intersection of a line and a circle
- Tangency of a line with a circle
- The intersection of two circles
- The center of a circle
- A point on a circle through which an extended radius would make a specified angle with an axis

These points can be determined by direct layout, or equations can be written to define them.

Lines are defined in the following ways:

- Through two points
- Through a point and tangent to a circle
- Tangent to two circles
- Through a point and making a specified angle with an axis
- Through a point and parallel to another line
- Through a point and perpendicular to a line
- Parallel to a given line and offset a given distance

Lines, too, can be established by layout procedures or by simple or quadratic equations.

Circles can also readily be defined mathematically. The more usual methods include definition by:

- Coordinates of center and length of radius
- The center and a line to which the circle is tangent
- The center and a point on the circumference
- Three points on the circumference
- The center and a circle to which the circle is tangent
- Intersecting tangent lines and length of radius

Trigonometry

The student of N/C should have facility in the recognition of problems involving the triangle and in the use of standard formulas to solve right, isosceles, and oblique triangles. He should also be proficient in the use of trigonometric functions and tables of the functions. True, computer programs perform the solution of such problems for continuous path programming; but positioning system programming, problem identification, and error analysis for continuous path demand more than a passing acquaintance with applied trigonometry.

INSTRUCTIONAL TECHNIQUES

References

Adams and Appallataqui. Applied Analytic Geometry. Douglas Aircraft Company.
National Aerospace Standard No. NAS 938. Washington: Aerospace Industries Association of America, Inc., 1963.
Numerical Control for Metalworking Manufacturing. Edited by Burnham Finney. New York: McGraw-Hill Book Co., 1960.
Shop-oriented trigonometry textbook
Shop-oriented algebra testbook

Handout Materials

Machine Axis and Motion Nomenclature (Handout Sheet No. 7-1)
Test questions and problems (Handout Sheet No. 7-2)

Audio-Visual Materials

Profit Robbers. 16 mm. color sound film, 20 min. (Milwaukee-Matic Mod. III), Germaine-Moore Machinery Co., 3200 S. Garfield, Los Angeles, Calif. 90022
Tapecraft. 16 mm. color sound film, 28 min. Republic Aviation Corp. (Attn: Public Relations Department), Farmingdale, L. I., New York 11735

Instructor Activities

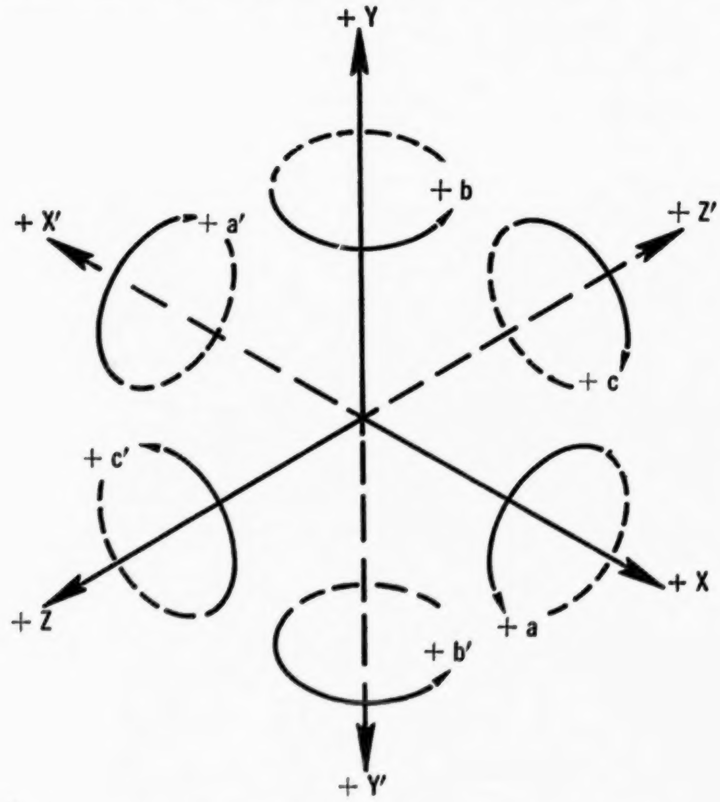
Provide assignment sheet, including problems in the location and definition of points, lines, and circles. Problems should include some requirements for trigonometric solution.

Student Activities

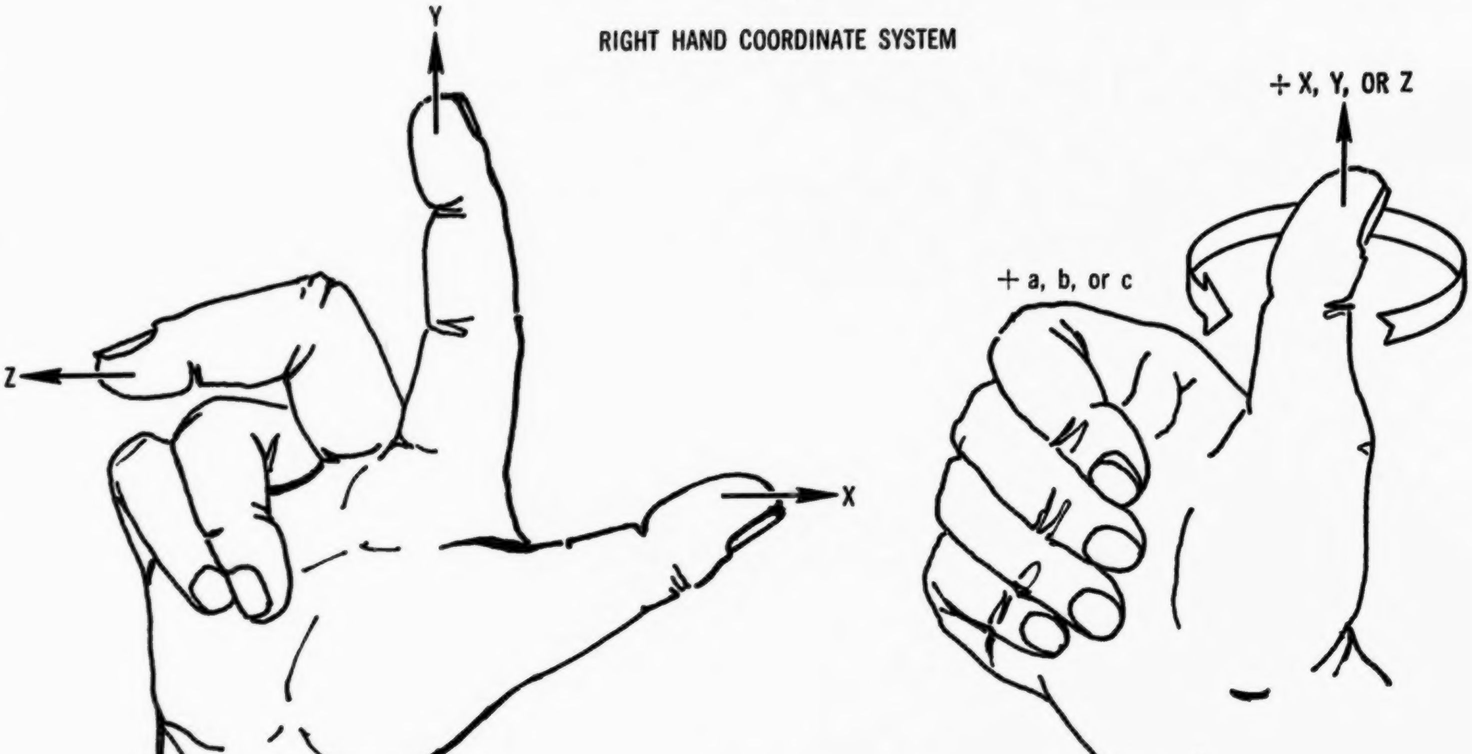
1. Work problems assigned.
2. Construct models showing axis designations for standard machine tools.

Handout Sheet No. 7-1

MACHINE AXIS NOMENCLATURE (p. 1 of 4)


+ Y
+ b
+ X'
+ a'
+ Z'
+ c
+ c'
+ X
+ Z
+ a
+ b'
+ Y'

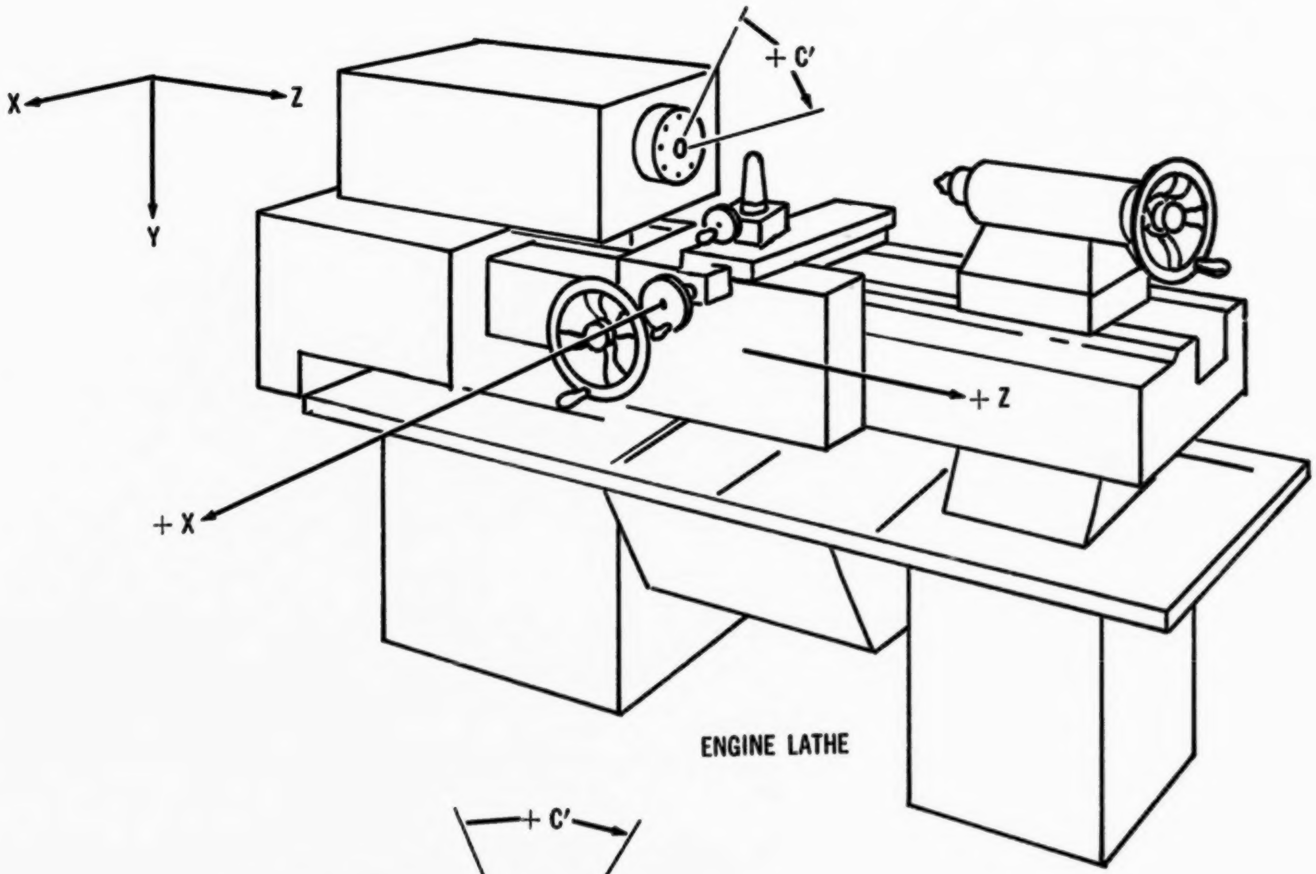
RIGHT HAND COORDINATE SYSTEM


Y
Z
X
+ X, Y, OR Z
+ a, b, or c

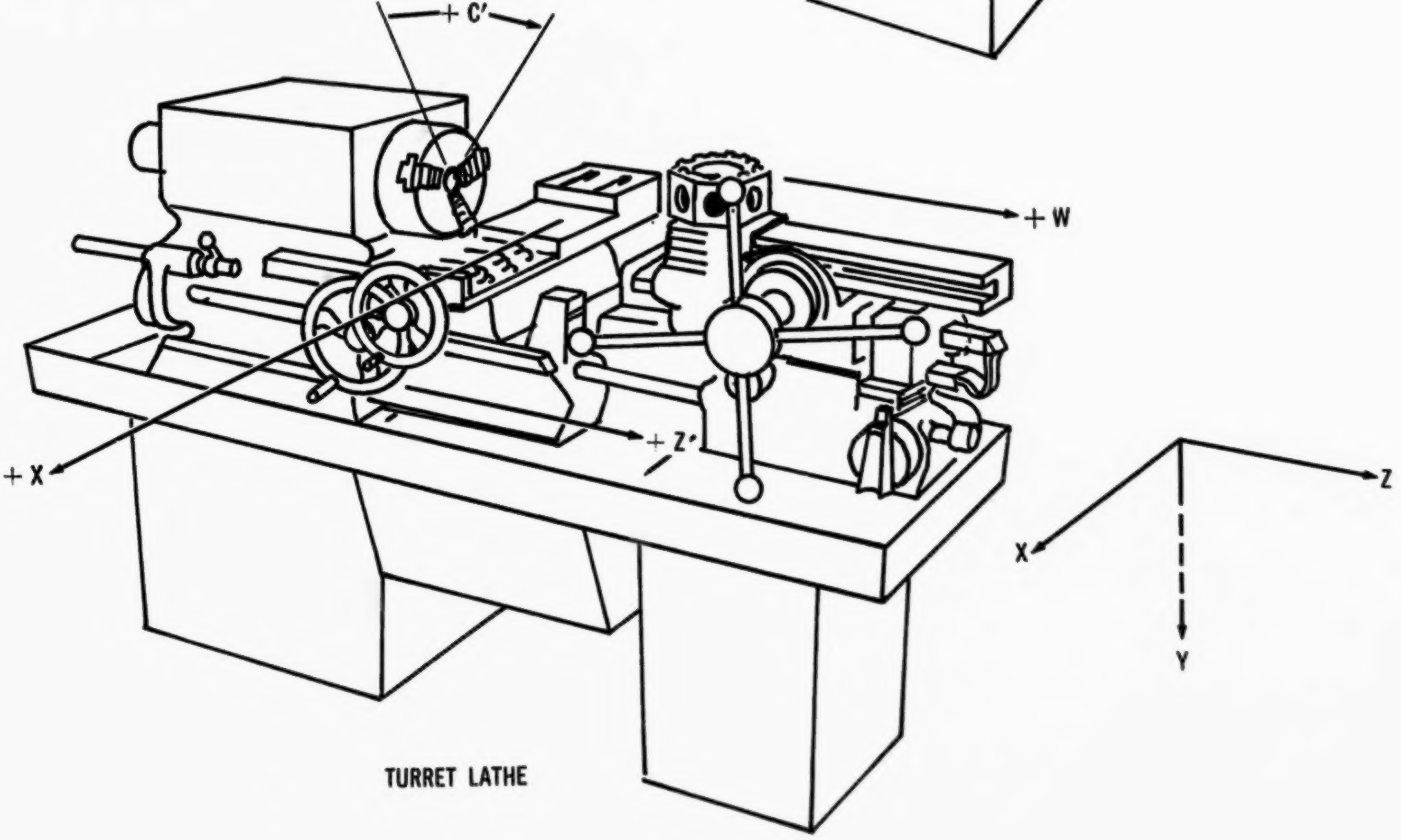
(2) RIGHT HAND COORDINATE SYSTEM

Handout Sheet No. 7-1

MACHINE AXIS NOMENCLATURE (continued)



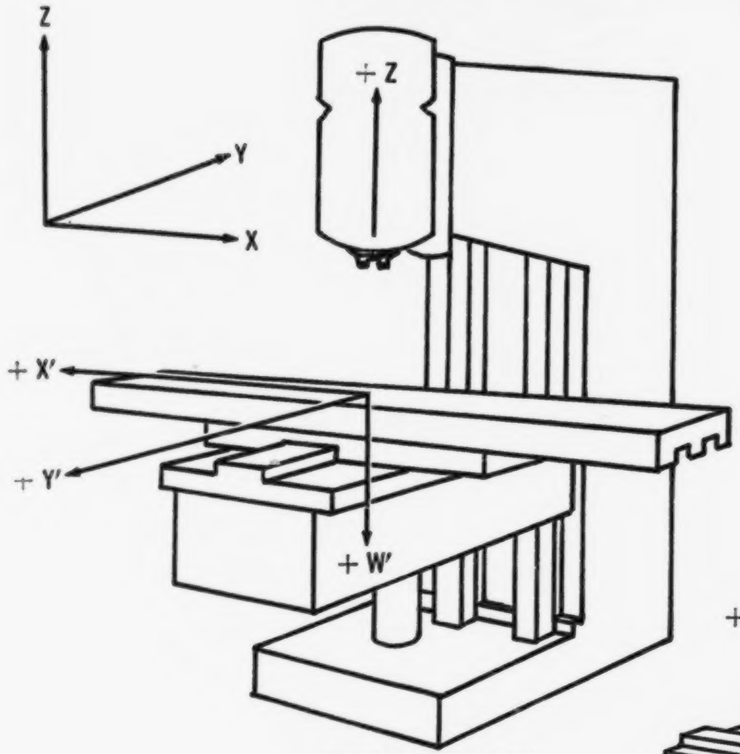
ENGINE LATHE



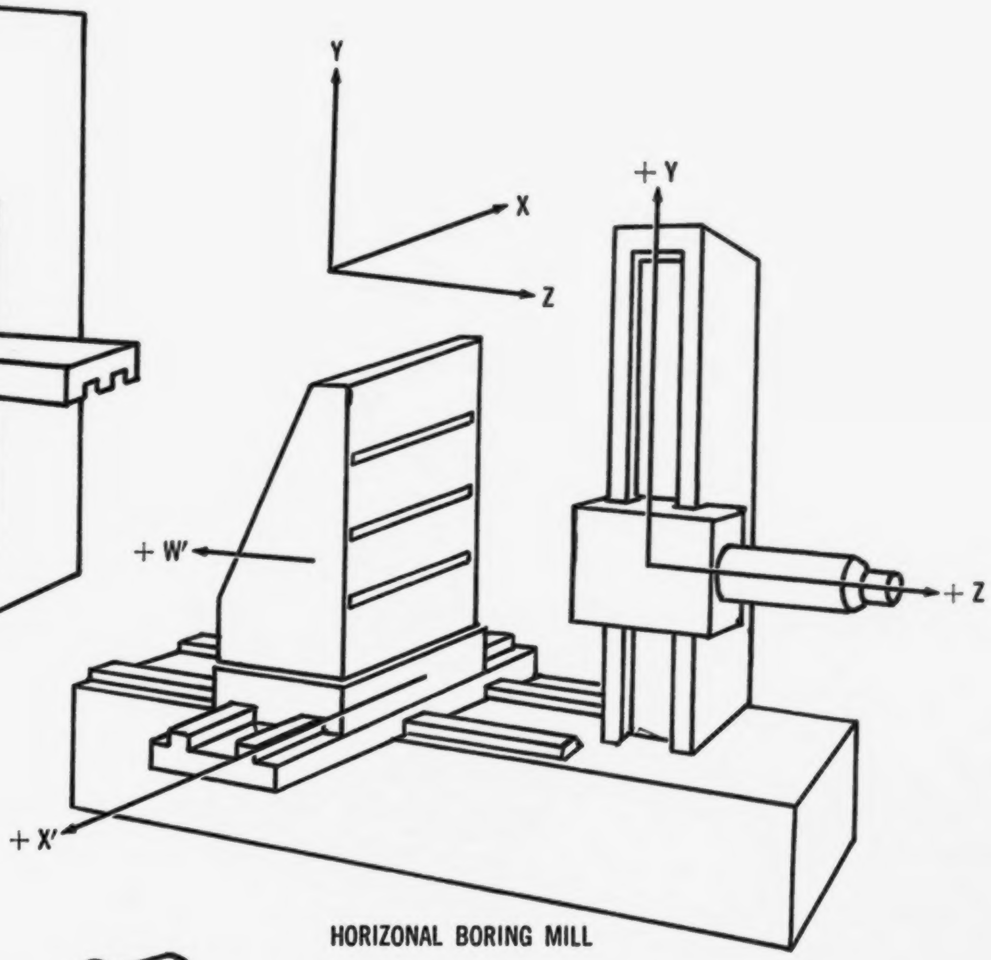
TURRET LATHE

Handout Sheet No. 7-1

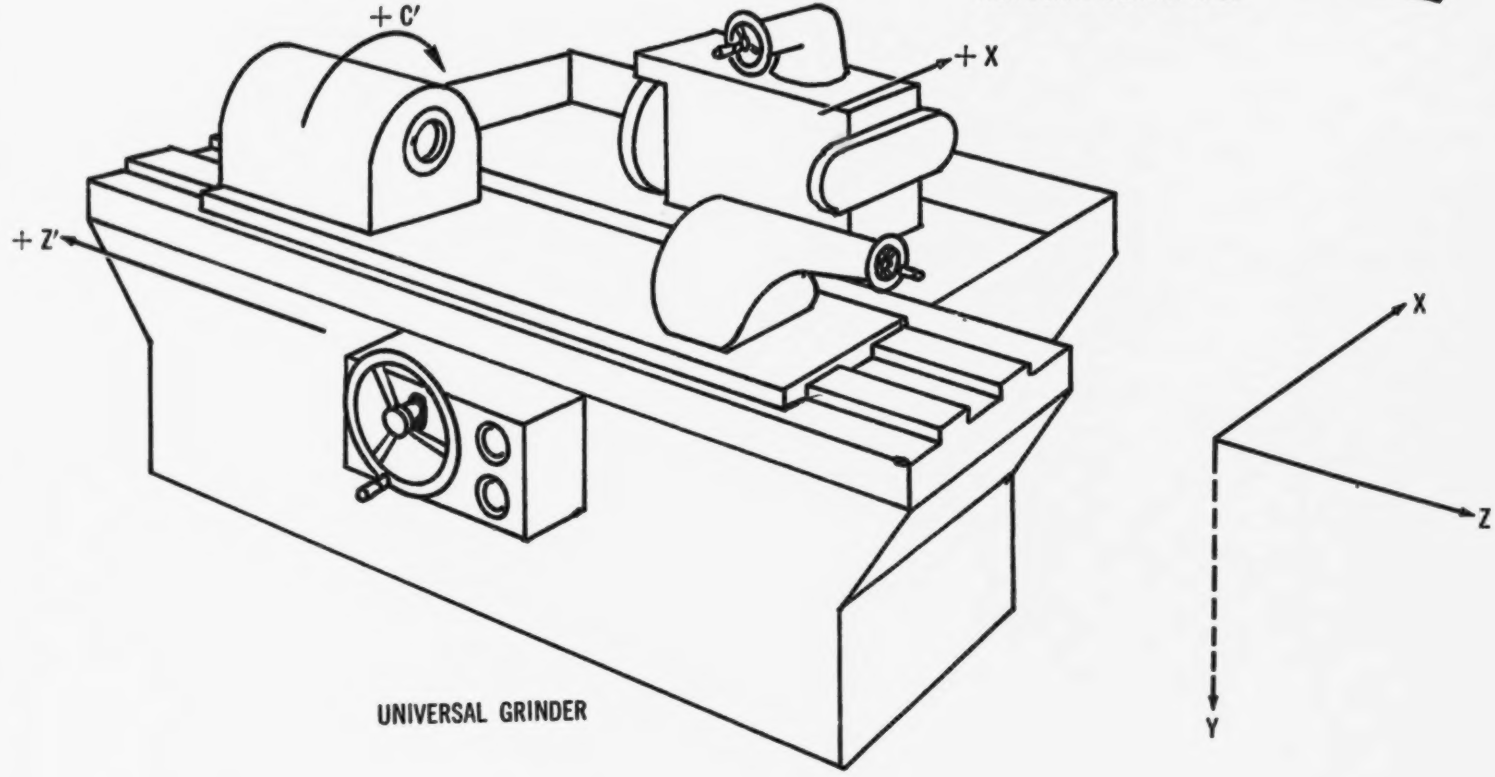
MACHINE AXIS NOMENCLATURE (continued)



VERTICAL KNEE MILL
DRILLING MACHINE
JIG BORER



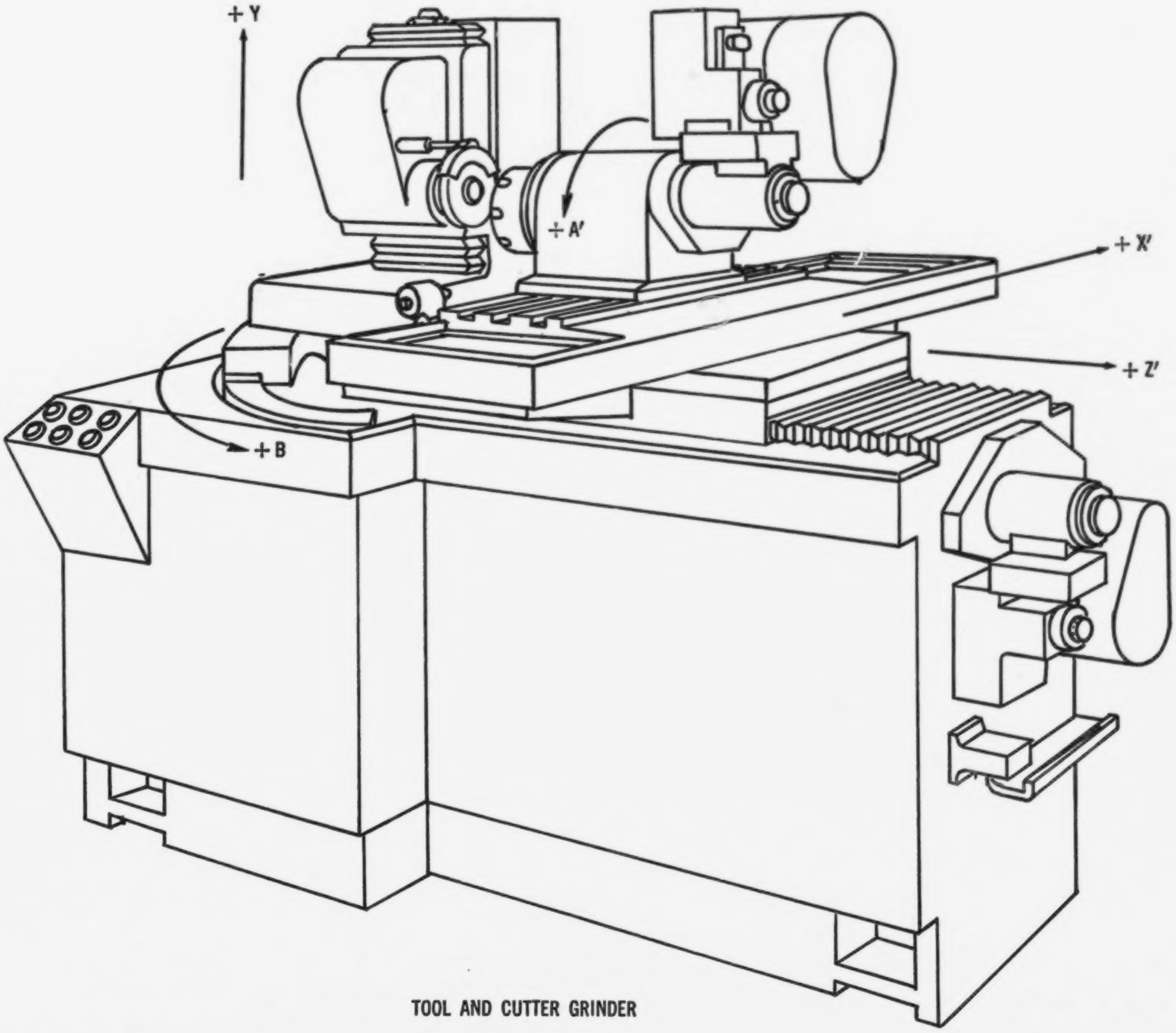
HORIZONAL BORING MILL



UNIVERSAL GRINDER

Handout Sheet No. 7-1

MACHINE AXIS NOMENCLATURE (continued)



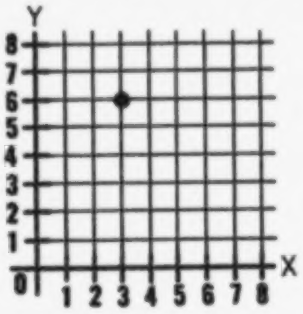
TOOL AND CUTTER GRINDER

Handout Sheet No. 7-2

TEST QUESTIONS AND PROBLEMS (p. 1 of 6)

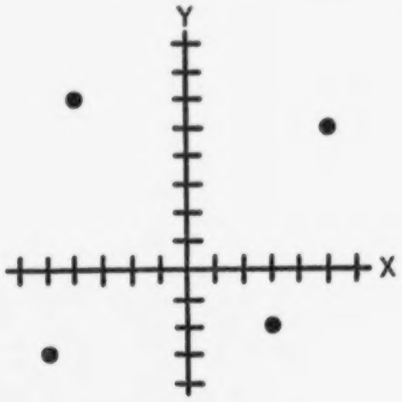
1. What are the coordinates of the point of the diagram below?

Answers: x = ______________ y = ______________



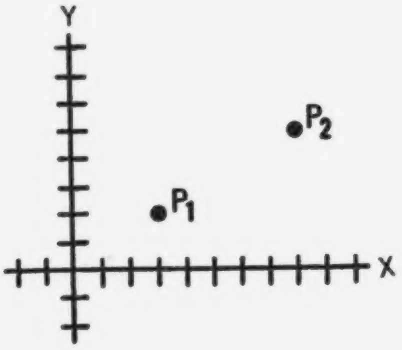
2. Give the coordinates of the four points indicated on the diagram below.

Answers: __________ __________ __________ __________



3. What are the x-coordinate, y-coordinate, and z-coordinate distances from Point P1 to Point P2?

Answers: Delta x = ________ Delta y = ________ Delta z = ________



Handout Sheet No. 7-2

TEST QUESTIONS AND PROBLEMS (continued)

Directions: Using a separate sheet of paper, solve the following problems showing all steps in the proper sequence. Lengths of sides are to be carried out to 4 decimal places. Interpolate all angles to the nearest second. Place answers only on the test sheets.

4. To what angle must the sides of Fig. A be machined? 4. ________

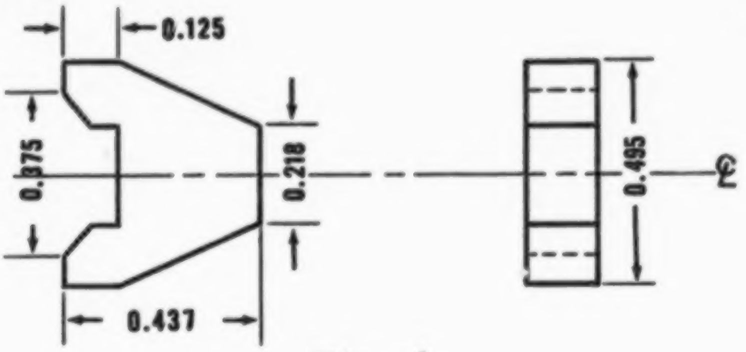


Fig. A

5. Find the angle needed to machine the skin shown in Fig. B. 5. ________

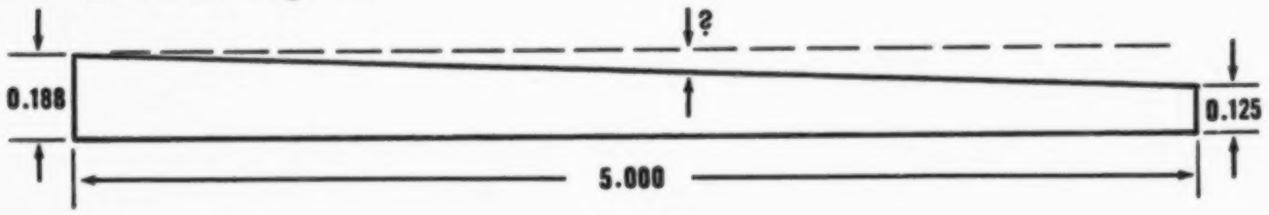


Fig. B

6. To what angle must the bevel at angle X in Fig. C be machined? 6. ________

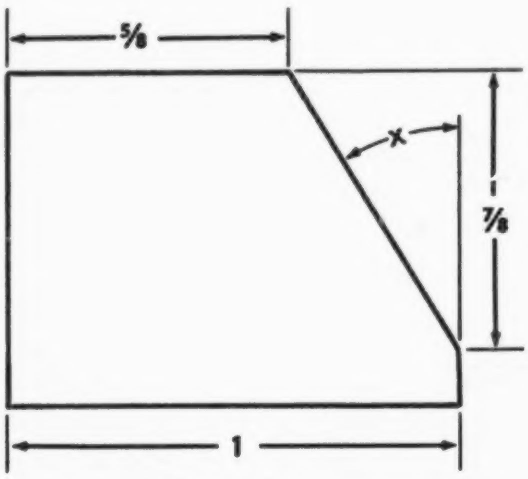


Fig. C

Handout Sheet No. 7-2

TEST QUESTIONS AND PROBLEMS (continued)

7. To what angle must the bevel at angle X in Fig. D be machined? 7. ____________

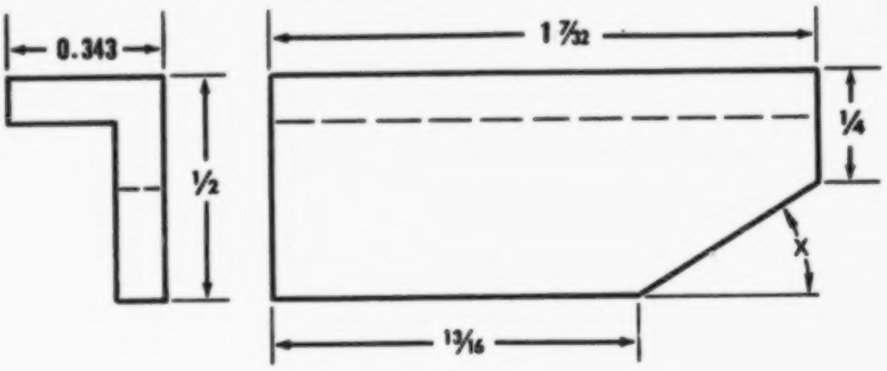

0.343
1/2
1 7/32
1/4
X
13/16

Fig. D

8. What is the included angle at end of the shaft in Fig. E? 8. ____________

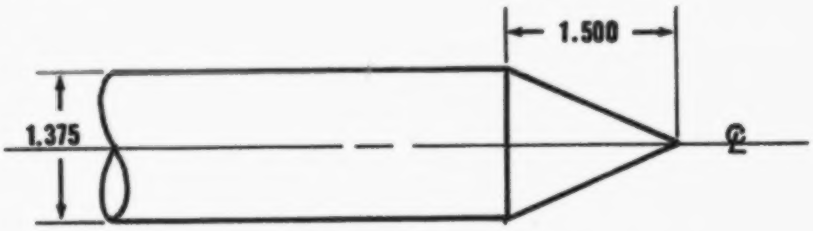


Fig. E

9. What is the length of side X in Fig. F? 9. ____________

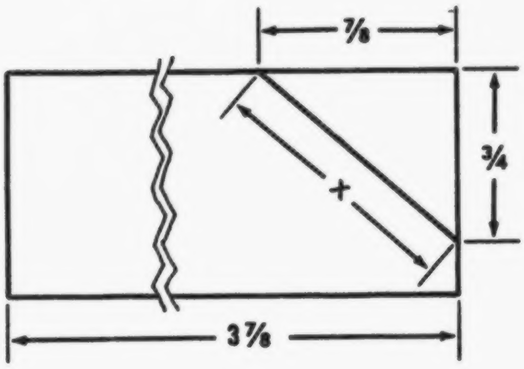


Fig. F

Handout Sheet No. 7-2

TEST QUESTIONS AND PROBLEMS (continued)

10. What is (a) the value of angle Φ in Fig. G; (b) the length of side X?

10a. ___________

10b. ___________

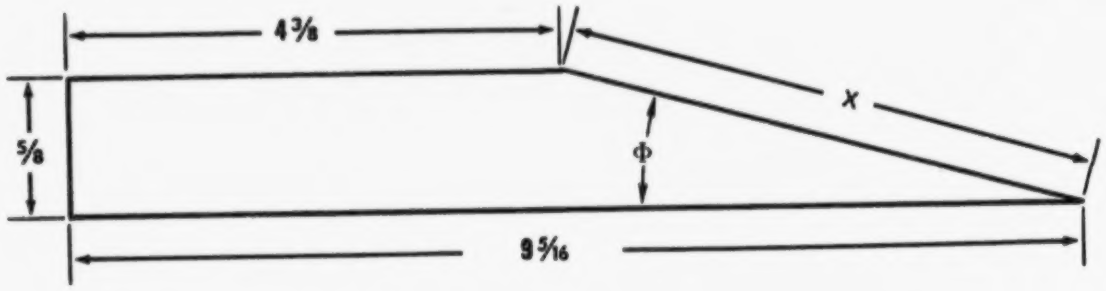


Fig. G

11. What is total length of part in Fig. H when it is finish machined?

11. ___________

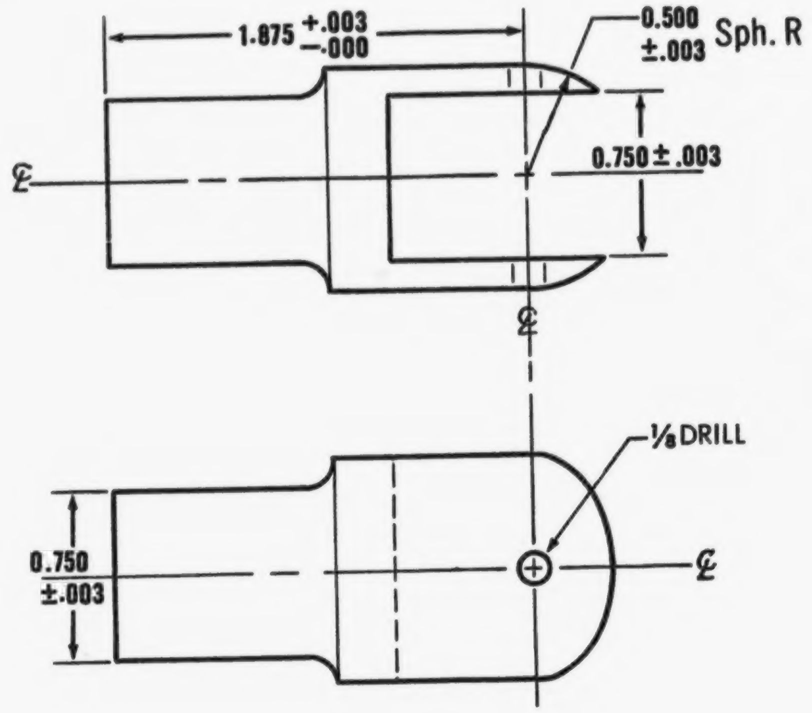
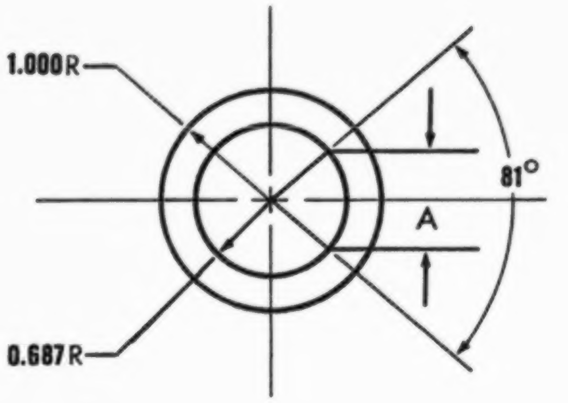

1.875 +.003 −.000
0.500 ±.003 Sph. R
0.750 ± .003
℄
℄
⅛ DRILL
0.750 ±.003
℄

Fig. H

Handout Sheet No. 7-2

TEST QUESTIONS AND PROBLEMS (continued)

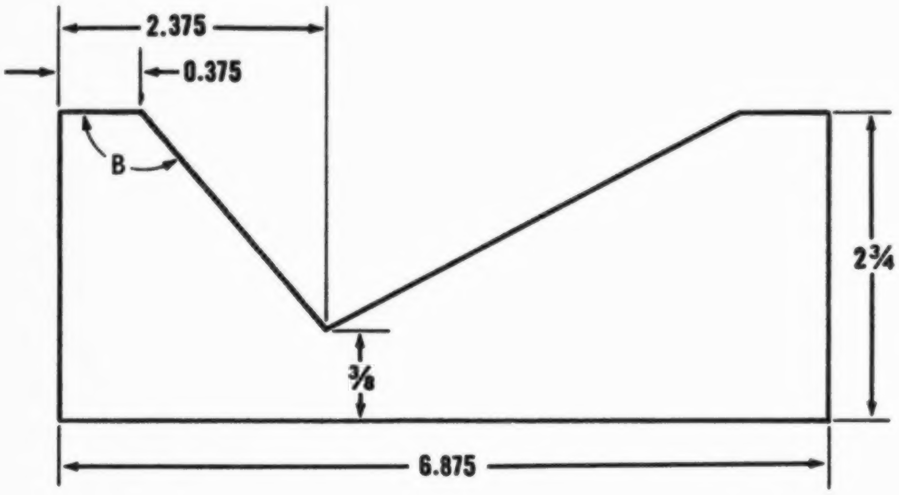
12. What is the width of the notch at A in Fig. I. 12. ____________



1.000R
0.687R
81°
A

Fig. I

13. Find angle B in Fig. J. 13. ____________



2.375
0.375
B
3/8
2 3/4
6.875

Fig. J

Handout Sheet No. 7-2

TEST QUESTIONS AND PROBLEMS (continued)

14. a. What is angle A in Fig. K? 14a. ____________

b. What is dimension X in Fig. K? 14b. ____________

c. With no tolerance allowed, what is the length and width of the part in Fig. K on a flat sheet of steel, before any machining? 14c. ____________

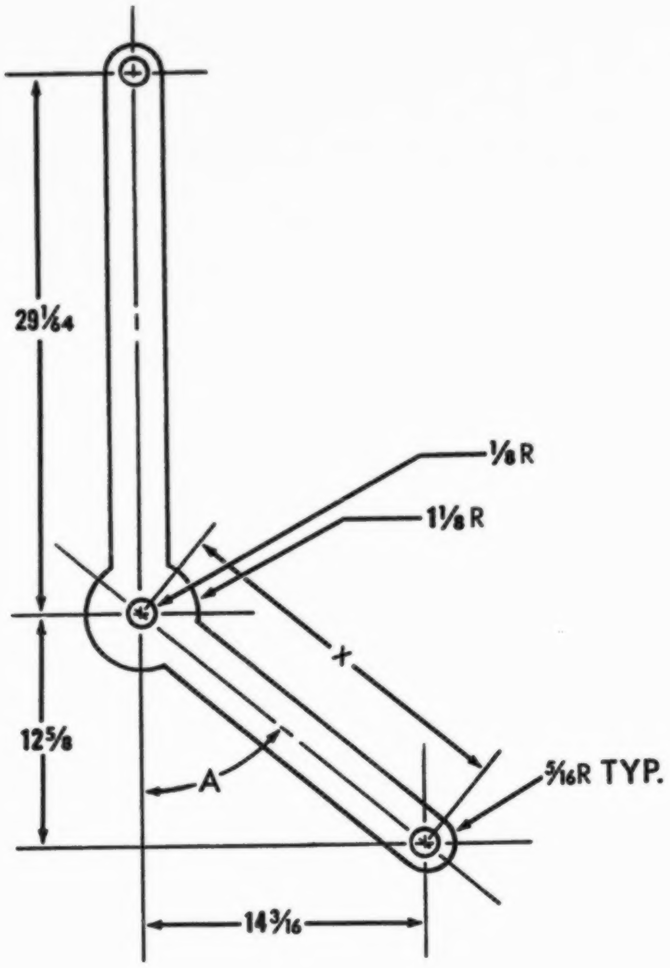

29 1/64
1/8 R
1 1/8 R
X
12 5/8
A
5/16 R TYP.
14 3/16

Fig. K

unit 8

NUMBER SYSTEMS

PLAN OF INSTRUCTION

Objectives

- To reacquaint the student with the various numbering systems used in modern calculation and communication
- To develop the student's understanding of binary arithmetic and of the applications of binary coding
- To familiarize the student with the standard tape codings
- To develop the student's facility for visually reading EIA 8-channel punched tape

Introduction

1. Discuss derivation and functional aspects of the base 10 system.
2. Explore with students the requirement for a means of numerical comparison, using examples of measurement and quantity. Identify with set theory.

Presentation

1. Interrelate major number systems of different bases, and develop the utility of each.
2. Present the binary system, including arithmetic methods.
3. Demonstrate binary-decimal and decimal-binary system conversions. Provide student exercises in conversion.
4. Explain binary coding techniques; relate them to straight binary and binary-coded decimal tape formats and codes.
5. Provide student exercises in reading (decoding) and writing (encoding) tape. Relate to alpha-numeric tape punch and to the Hollerith and Rem-Rand card codes.

RESOURCE UNIT

The decimal, or base 10, number system is the system most commonly in use today. This system probably evolved from the use of the ten fingers as aids in the counting process. The digits 0 through 9 that we use are simply ten symbols for the ideas of quantity; from them a positional system has been developed in which the placement of the symbols indicates the magnitude of the total number represented.

The decimal system, however, is being supplemented and even supplanted in some fields by newer systems which offer improved utility and efficiency for their purposes. Many, but not all, of the new systems are based on the use of 2 and powers of 2, just as the decimal system is based on 10 and powers of 10. The use of various other bases results from the search for the system most suitable for a particular application. The base 2 systems are called binary systems.

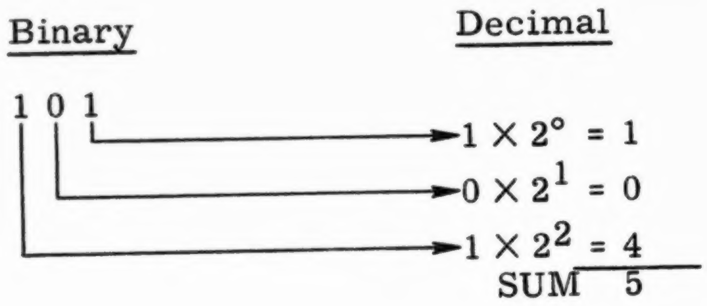
Some parallels can be drawn between systems that will help one to understand them and to appreciate the value of the new systems in terms of applicability and ease of operation. The decimal system uses ten symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. A value greater than nine is expressed by the use of the same symbols placed to the left. The position indicates that each has been multiplied by ten, or 10^1. Thus to note a value of one more than 9, the notation 10 is used; thence, 11, 12, and on through 19. Then the second column takes 2, showing 20, 21, and so on. Eventually 99 is reached and a third figure is again placed at the left, with a positional multiplier of 10^2 or 100. The system can be developed in this fashion indefinitely.

The same technique could be used for counting with any other set of symbols to any desired base. For instance, the base four could be chosen, with the four symbols in order of their value being a, b, c, and d. The count would then proceed ba, bb, bc, bd, ca, cb, cc, cd, da, db, dc, dd, bab, bac, and so on. The positional multiplier in this system would be the successive powers of four. And without much trouble, translation to or from the decimal system could be effected.

Binary Arithmetic

Binary systems have found a great number of applications because of the simplicity of using the base 2. The concept can be compared to an electric light, which has two states--off or on. The symbols chosen are 0 and 1, and 0 represents the off condition, 1 the on condition. Besides simplicity, binary codes have an adaptability to many two-condition situations: e.g., black or white; a solid card or a hole in it; a magnetic charge or none; an electrical current or no current; and many more. There are only two conditions to be represented, 0 or 1. The binary system in its simplest form is a positional system, wherein the positional multiplier is again the powers of the base 2, also called the radix.

Conversion from a binary number to its decimal equivalent can be shown in these terms as follows.



The equivalent of 101 binary is 5 decimal. Additional digits to the left in the binary number simply involve use, in the conversion, of the successively higher powers of 2, 2^3(8), 2^4(16), 2^5(32), and so on.

The reverse translation may be simply illustrated thus:

Divide the decimal number	5 by 2 = 2 remainder 1
Divide the quotient again	2 by 2 = 1 remainder 0
Divide again	1 by 2 = 0 remainder 1

The column of remainders, read upward, is the binary; the dividing process is continued until the quotient is zero.

Addition of binary numbers requires only two rules:

a. 0 plus 1 equals 1

b. 1 plus 1 equals 0; carry 1 to the next column to the left.

Example:

Binary	Decimal
1 1 1	7
+ 1 0 0	+ 4
1 0 1 1	11

Subtraction is performed in reverse with four rules:

a. 1 minus 0 equals 1

b. 1 minus 1 equals 0

c. 0 minus 0 equals 0

d. 0 minus 1 equals 1; with 1 borrowed from the column to the left.

Borrowing involves writing 1 above each 0 to the left of the first 0, making the specific 0 into 1 0. The 1 is ultimately borrowed from the extreme left, removing that bit from further coordination.

Examples:

Binary	Decimal	Binary	Decimal
		1*	
1 1 1	7	1 0 0 1	9
- 1 0 0	- 4	- 1 1 1	- 7
1 1	3	1 0	2

* Borrowed

Binary Codes

The binary code represented above uses only two symbols or marks: 0 and 1. For convenience, these marks 0 and 1 are called "bits," a contraction of "binary digits." Any decimal number may be represented by using these bits, but as the numbers become larger the representation becomes more and more cumbersome, especially where visual readout or manual input is necessary. To overcome this problem, binary-coded decimals have been devised, in which each digit of the decimal is represented by a four-bit binary number, as follows:

Decimal	Binary Coded Decimal
10	0 0 0 1 0 0 0 0
21	0 0 1 0 0 0 0 1
863	1 0 0 0 0 1 1 0 0 0 1 1

Fig. 8-1 shows how each of these numbers is punched into a four-track tape. Each track has a value in terms of the powers of 2; a hole indicates bit 1, lack of a hole indicates bit 0.

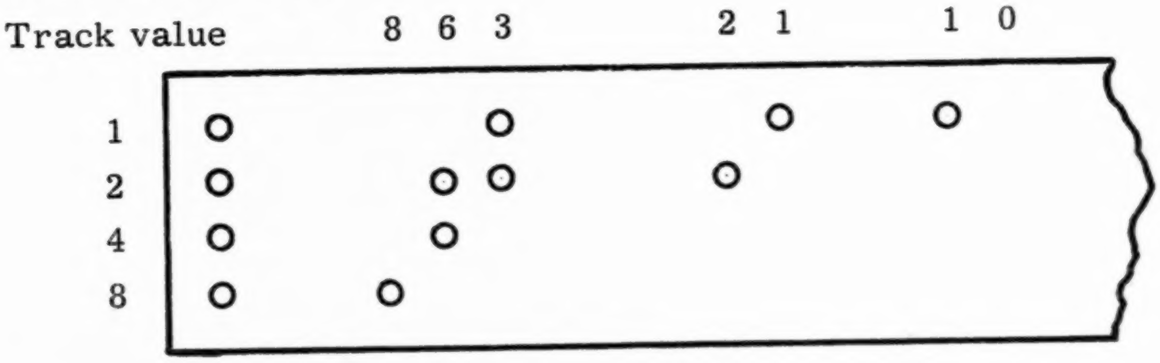


Fig. 8—1. Four-track binary tape

The largest decimal number that can be indicated in any vertical row is 15, but the largest required is 9 in this application. A similar arrangement could be used with an array of control lights (off or on) on a display panel, so that internal settings on a control system or computer could be read out directly.

Punched tape codes have been established that permit use of straight binary input (Fig. 8-2) and the use of binary-coded decimals (Fig. 8-3).

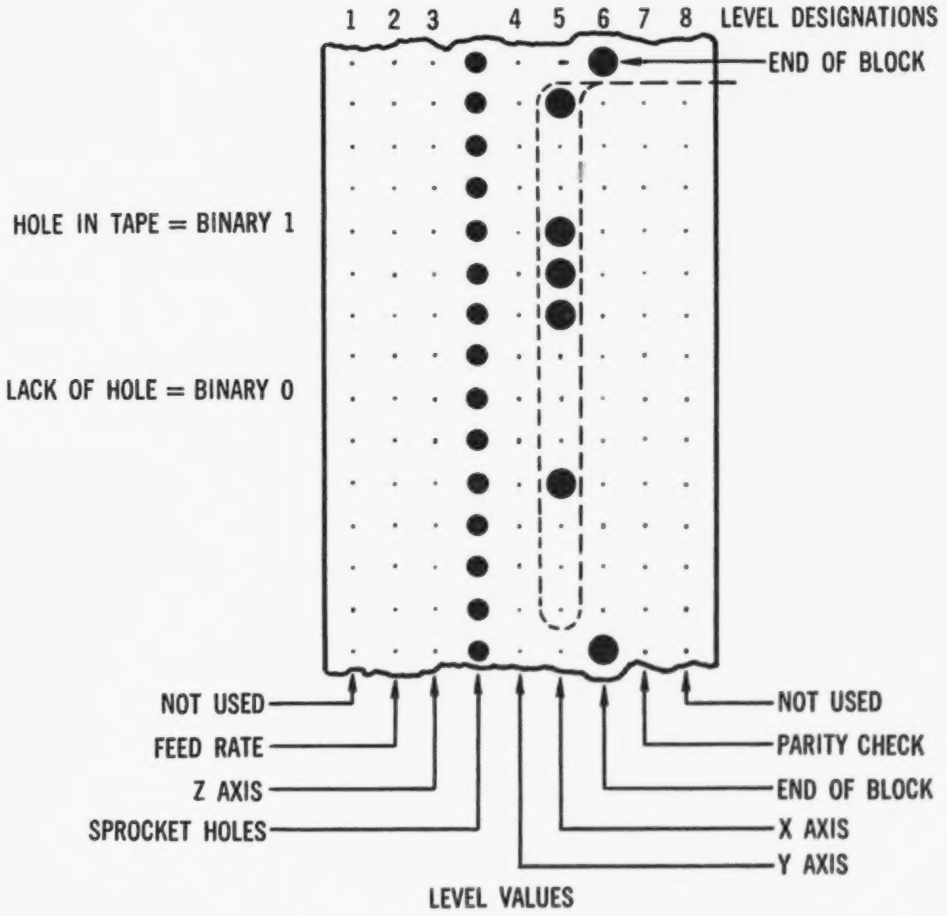

1 2 3 4 5 6 7 8 LEVEL DESIGNATIONS
END OF BLOCK
HOLE IN TAPE = BINARY 1
LACK OF HOLE = BINARY 0
NOT USED
FEED RATE
Z AXIS
SPROCKET HOLES
NOT USED
PARITY CHECK
END OF BLOCK
X AXIS
Y AXIS
LEVEL VALUES

Fig. 8—2. Eight-track straight binary tape

Such tapes are used for machine tool control as well as for computer input and output. On the straight binary tape, as used in a number of early continuous path control units, each axis or function (such as feed or speed) designation ran the length of the tape in a specified track. The straight binary-coded tape was widely used, and it will continue to be found until all the control systems using it are discarded. The more recent systems use the EIA standard binary-coded decimal tape for both positioning systems and continuous path systems. The EIA standard uses an eight-track tape. At some future date, code revisions now under discussion may become effective, initially in computer systems connected to data links.

Fig. 8-3 illustrates the present EIA standard tape. The tracks are numbered, to the left, 1 through 8 with the sprocket holes aligned between rows 3 and 4. The first four tracks have binary values of 1, 2, 4, and 8, respectively. Track 5, which may be labeled as either the "P" or "CH" track, has a special function; it is punched automatically so that every row of information will have an odd number of holes. By this means the action of the tape punch may be checked; any row having an even number of holes is said to contain a "parity error." Track 6 has a value of zero; track 7 is designated the "x" track; and track 8 indicates only "end of block," which is also the carriage return signal for the electric typewriter.

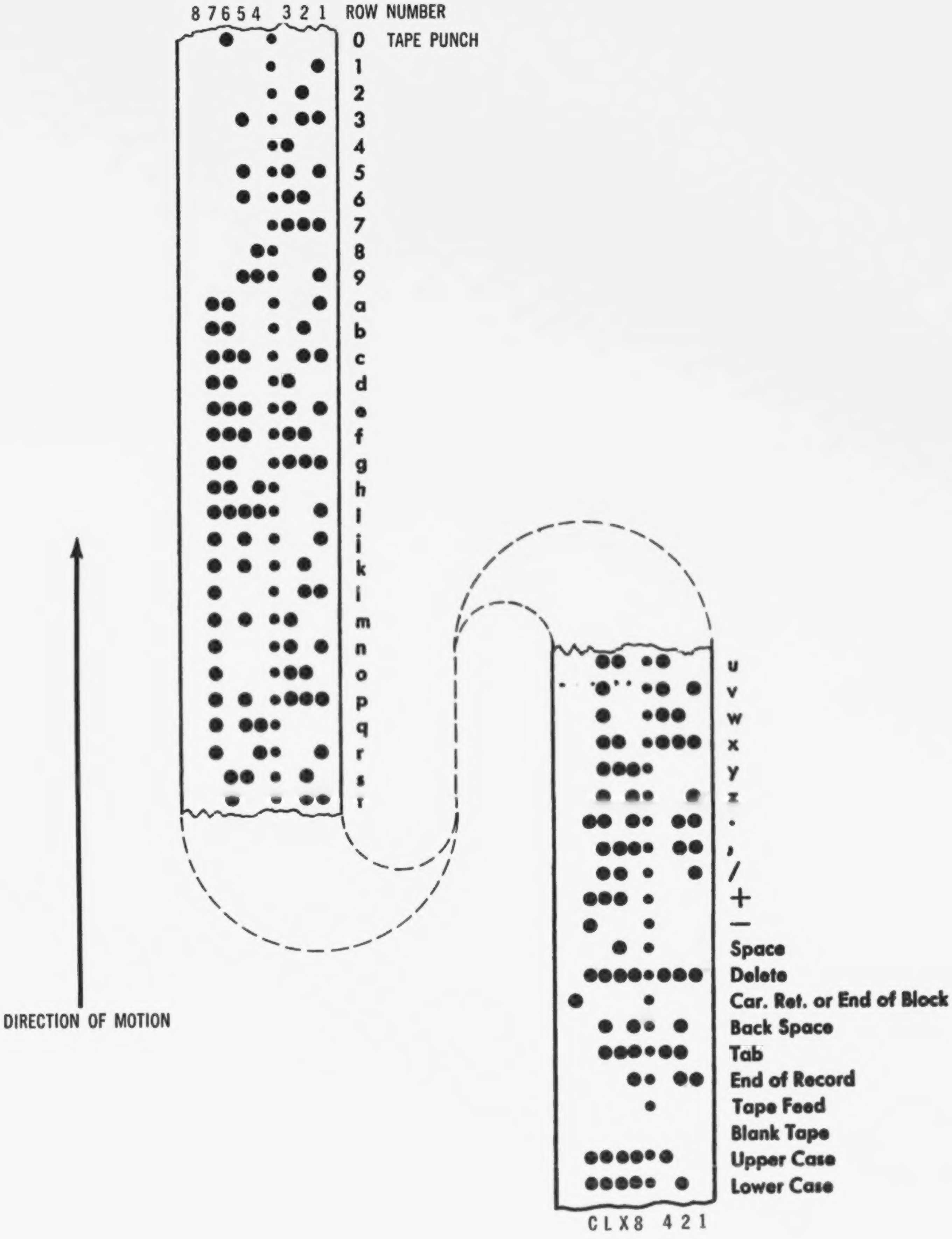

8 7 6 5 4 3 2 1 ROW NUMBER
TAPE PUNCH
0
1
2
3
4
5
6
7
8
9
a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p
q
r
s
t
u
v
w
x
y
z
.
,
/
+
—
Space
Delete
Car. Ret. or End of Block
Back Space
Tab
End of Record
Tape Feed
Blank Tape
Upper Case
Lower Case
C L X 8 4 2 1
DIRECTION OF MOTION

Fig. 8—3. EIA standard coding for 1-inch 8-track tape

Other Numerical Notations

A wide variety of numerical notations have been developed for general and special uses. They can be applied to many computer functions and capabilities of computers, such as digital programming, random-access core memories, and internal data-storage systems. A brief description of some of these notations follows. Fig. 8-4 affords a comparison of them.

Sexadecimal Notation. Four-track binary coding, as previously described, permits direct expression of any decimal number up to 15 in each row. Thus, the standard 4-bit circuitry found on equipment using this form of input or output can be adapted to express any of the sixteen numbers from 0 to 15. A sexadecimal notation has been developed to take advantage of this capability.

Cyclic Notation. Cyclic notation, or Gray coding, was devised to reduce the probability of system error by permitting only one bit at a time to change when progressing from one number to the next. To illustrate, in ordinary binary code the number that follows 0111 is 1000, requiring all four bits to change. An error in equipment operation could result in any number between 0000 and 1111, sixteen possibilities. The cyclic notation rearranges the code to avoid such a situation. Binary notation can be converted to cyclic notation by adding the binary number to itself, with the second indexed one place to the right, and without carrying. Thus, binary 1001 and 1110 are converted to cyclic as follows:

$$\begin{array}{rcr} 1\,0\,0\,1 & \text{(binary)} & 1\,1\,1\,0 \\ \underline{\quad 1\,0\,0} & \text{(cyclic)} & \underline{\quad 1\,1\,1} \\ 1\,1\,0\,1 & & 1\,0\,0\,1 \end{array}$$

Excess 3 Code. The "Excess 3" code is used to simplify the subtraction process. It is the same as pure binary except that each number is the binary number plus 011 (three). In this code the binaries for zero and nine are opposite, 0011 and 1100. The same is true of the other pairs that add to 9: four and five, three and six, two and seven, one and eight. By facilitating subtracting and complementing, the computer or control system circuitry can be greatly simplified, and the chance of error correspondingly reduced.

The 1, 2, 4, 7 System. In the 1, 2, 4, 7 system only two 1's are used to express any number. In Fig. 8-4 it will be noted that after 6 is reached, another column is used to encode 7, rather than using three 1's. Again, this gives better capability for checking circuits and improved accuracy, compared to the pure binary coding.

The Floating Decimal. The "floating decimal" is not an additional code, but a term that has been applied to a technique of expressing numbers, especially very large or very small ones. The number is expressed by using its significant figures times a common multiplier with exponent. Thus, the multiplication of 1,200 × 800 would be shown as $(1.2)\ (10^3) \times (8)\ (10^2)$. The significant figures are multiplied (9.6) and the exponents of 10 are added, giving $(9.6)\ (10^5)$, which expands to 960,000. The multiplying and adding operations are reduced, and hence both the circuitry and the time required are reduced.

Decimal	Binary	Cyclic	Binary-coded Decimal	Sexa-decimal	1,2,4,7	Excess 3	Decimal
0	0000	0000	0000	0	0000	0011	0
1	0001	0001	0001	1	0001	0100	1
2	0010	0011	0010	2	0010	0101	2
3	0011	0010	0011	3	0011	0110	3
4	0100	0110	0100	4	0100	0111	4
5	0101	0111	0101	5	0101	1000	5
6	0110	0101	0110	6	0110	1001	6
7	0111	0100	0111	7	1000	1010	7
8	1000	1100	1000	8	1001	1011	8
9	1001	1101	1001	9	1010	1100	9
10	1010	1111	0001 0000	u	1100	1101	10
11	1011	1110	0001 0001	v	10001	1110	11
12	1100	1010	0001 0010	w	10010	1111	12
13	1101	1011	0001 0011	x	10100	10000	13
14	1110	1001	0001 0100	y	11000	10001	14
15	1111	1000	0001 0101	z	100000	10010	15
16	10000	11000	0001 0110	10	100001	10011	16
17	10001	11001	0001 0111	11	100010	10100	17

Fig. 8—4. Commonly used code notations

Purposes of Numerical Coding

Binary arithmetic has two major advantages. First, simplicity--many devices have more or less permanent two-state variability. And second, speed of computation--the utter simplicity of the systems permits extremely rapid processing of information. The necessity for both input and output communication in N/C makes special codings valuable. The machine operator must have a means of reading the tape so that he may perform his tasks correctly. On systems where reading was difficult, such as straight binary coded tape, auxiliary procedures had to be devised, lest much time be wasted when machines have to "cut air" while a point of malfunction is precisely located.

Each person engaged in programming, setup, operation, and maintenance of N/C equipment must be able to recognize the numerical coding used in the tape or in the circuitry to the extent that his duties are affected by the coding. And an understanding of binary coding is also essential in all the phases of tool selection, designation, and setup that are not controlled by the tape. The key and ring codings or tooling used in connection with machining centers afford examples of these requirements.

INSTRUCTIONAL TECHNIQUES

References

National Aerospace Standard Nos. NAS 943 and NAS 955. Washington: Aerospace Industries Association of America, Inc., 1963.
Numerical Control in Manufacturing. Edited by F. W. Wilson. New York: McGraw-Hill Book Co., 1963.
Numerical Control for Metalworking Manufacturing, Edited by Burnham Finney. New York: McGraw-Hill Book Co., 1960.
Johnson, W. B. "Numerical Control Standards: An Unnecessary Dilemma," Tool and Manufacturing Engineer (July, 1965).
Peacock, J. "1 + 1 = 10, or Binary Numbers Made Easy," American Machinist/Metalworking Manufacturing (July 25, 1960).

Handout Materials

Copy of Figure 8-4
Form for tape-encoding practice (Handout Sheet No. 8-1)
Hollerith Code (Handout Sheet No. 8-2)

Audio-Visual Materials

Tape codes (overhead projector transparencies, teacher-prepared)
Tape samples for tape-reading drill

Student Activities

1. Solve problems in binary arithmetic, especially decimal-binary and binary-decimal conversions.
2. Participate in tape-reading and tape-encoding exercises.
3. Participate in tool coding exercises using both key and ring codes. (See illustrations in Unit 4.)

Handout Sheet 8-1

TAPE WORKSHEET

123 o 45678	123 o 45678	123 o 45678
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
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000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
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000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000
000 o 00000	000 o 00000	000 o 00000

Handout Sheet No. 8-2

HOLLERITH CODE

Sym	Punch Line No.	Sym	Punch Line No.	Sym	Punch Line No.	Sym	Punch Line No.
A	12, 1	M	11, 4	Y	0, 8	# =	3, 8
B	12, 2	N	11, 5	Z	0, 8	@	4, 8
C	12, 3	O	11, 6	0	0	/ +	12
D	12, 4	P	11, 7	1	1	.	12, 3, 8
E	12, 5	Q	11, 8	2	2	⌘)	12, 4, 8
F	12, 6	R	11, 9	3	3	-	11
G	12, 7	S	0, 2	4	4	$	11, 3, 8
H	12, 8	T	0, 3	5	5	*	11, 4, 8
I	12, 9	U	0, 4	6	6	/ &	0, 1
J	11, 1	V	0, 5	7	7	,	0, 3, 8
K	11, 2	W	0, 6	8	8	% (	0, 4, 8
L	11, 3	X	0, 7	9	9		

unit 9

PART PROGRAMMING

PLAN OF INSTRUCTION

Objectives

- To acquaint the student with the language and formats involved in part programming for positioning systems
- To alert the student to the close coordination required between design engineering, planning, programming, and machine operation
- To identify the procedures and equipment necessary to production of a control tape
- To familiarize the student with the essential features of typical parts programmer's manuals

Introduction

1. Review planning procedures used to establish route sheets or part method outlines.
2. Develop an operation analysis for conventional equipment.
3. Relate conventional procedures and N/C procedures with respect to the varieties of information required by a machine tool and the communication of the information by control tape.

Presentation

1. Introduce the varieties of information to be communicated by tape.
2. Review tape formats for binary-coded decimal (BCD) tape codings, including fixed sequential, tab sequential, and word address.
3. Describe tape preparation procedures and communication problems. Relate them to data processing techniques.
4. Describe, and demonstrate if possible, types of tape and card punches.
5. Discuss absolute and incremental methods of defining machine movements.
6. Illustrate standard printout formats for each of the standard tape codings.
7. Identify preparatory and auxiliary function codes and concepts.

8. Review N/C drawing callouts and the techniques used to identify point coordinates and to designate machine axes.
9. Review tool coding methods.

RESOURCE UNIT

The techniques used in programming parts for N/C production are fundamentally but extensions of the techniques used for conventional operations by planners, methods engineers, process engineers, and tool planners or engineers. Both past and present practices involve the analysis of parts manufacturing possibilities and the selection of the best sequence of fabrication operations. The major operations are outlined in general terms on a form variously called a step procedure, a route sheet, bench orders, or other titles.

Fabrication Outlines

The plan or routing for a conventional machine job includes tools used, speeds and feeds, and other data to guide the operator in setup and performance. Usually, conventional-shop personnel were free to select correct alternatives for both setup and operation, relying on their own experience or training. Any changes made were supposed to be reported to the planning department for incorporation into the manufacturing practice records. Under these conditions, shop procedure would tend to improve steadily. Unfortunately, some changes would not be reported, while others would be a reversion to past practices or a diversion from planned tooling sequences. Cost analyses, quality appraisals, and time studies all demonstrated the wisdom of close adherence to planned sequences. Emphasis on the development and maintenance of improved methods led directly to the concept of numerical control.

The increase in predetermined tooling and performance relationships led, of course, to curtailment of permissiveness in the shop phases of production. The choice of specific machining practices is an exercise in selection among alternatives in which choices of materials, processes, and tooling affect quality, quantity, and cost of production.

Initial Steps in N/C Programming

With N/C, preselection is applied to the organization of most of the performance elements of each operation. Performance was once the domain of the skilled machinist in the shop, but no longer. Improved machine capabilities demand overall planning in pace with their improvement. And the planners must understand all the capabilities of N/C, as well as know correct machining sequences to make correct applications and to ensure an optimum program.

Once a part is assigned to N/C for machining, the programmer takes over. He identifies the features of the part and defines the sequences of tooling. The part features are given designations--Hole 1, Hole 2, Side 1, Slope 2, and so forth--not necessarily in the order in which they will be performed. (See Fig. 9-1.)

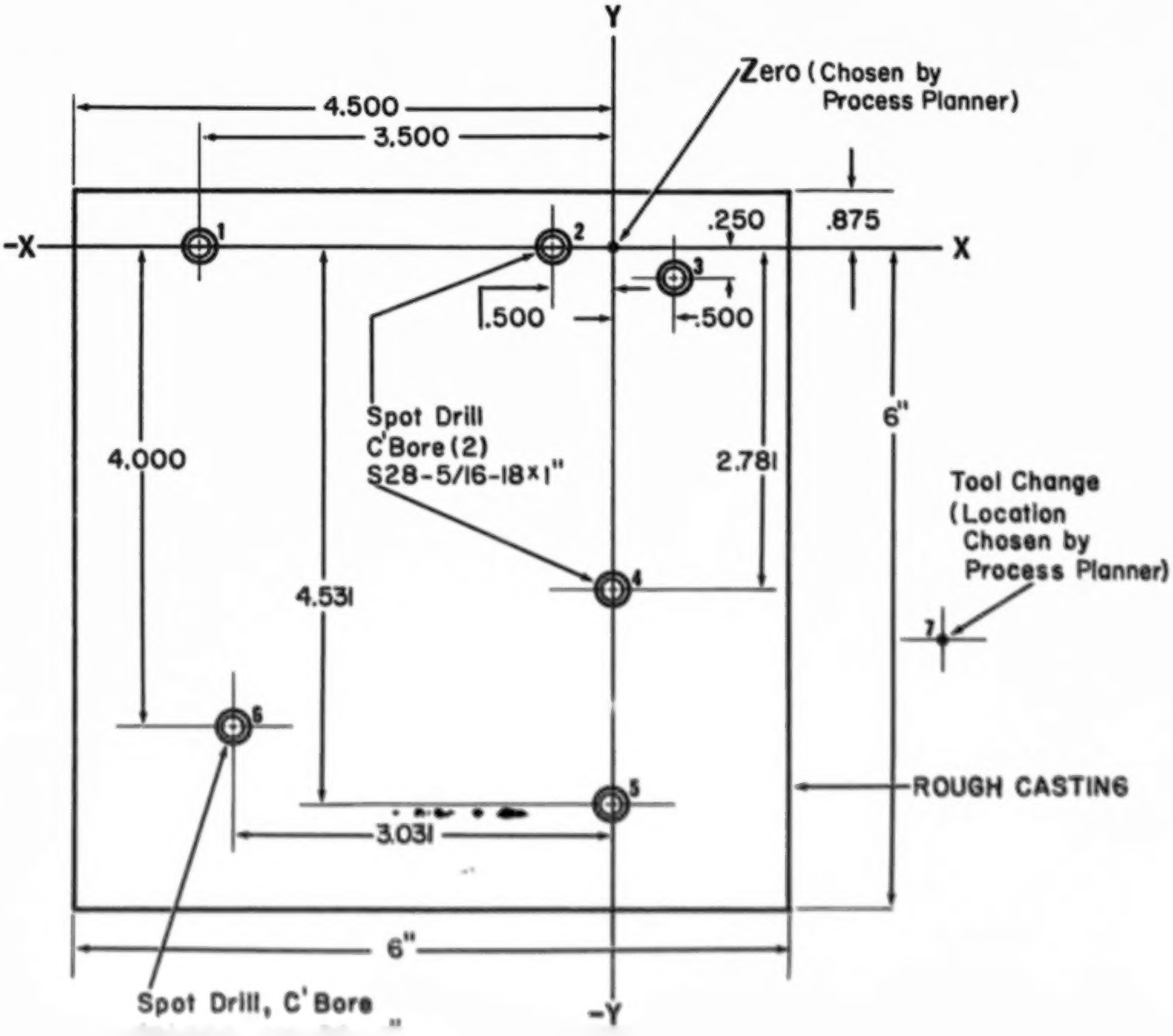
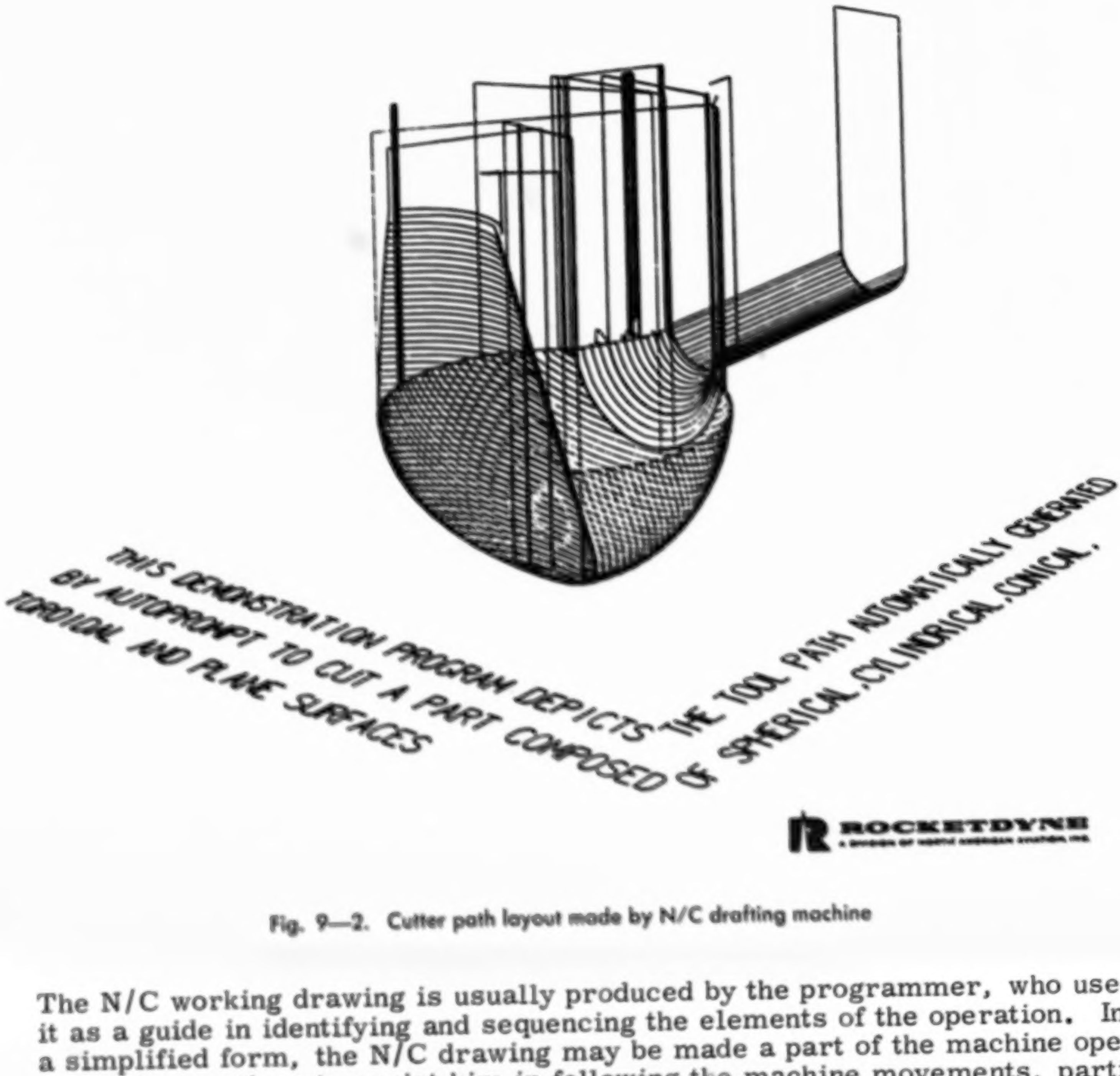

Y
Zero (Chosen by Process Planner)
4.500
3.500
.250
.875
-X
X
1
2
3
.500
.500
Spot Drill
C'Bore (2)
S28-5/16-18×1"
4.000
2.781
6"
Tool Change (Location Chosen by Process Planner)
4
7
4.531
6
5
ROUGH CASTING
3.031
6"
Spot Drill, C'Bore
-Y

Fig. 9—1. Sample part drawing

This phase involves the preparation and use of an N/C drawing, which may be any type from a sketch to a detailed mechanical drawing, with perhaps some use of pictorial or perspective techniques. (This planning drawing should not be confused with the complex drawings that can be produced by the N/C draftin machine or x-y plotter. Such machine drawings are produced with the same control tape, or a similar one, that is used for the machine operation and are used for such purposes as to depict the cutter path. Fig. 9-2 is an example of an N/C tape-controlled drawing).


THIS DEMONSTRATION PROGRAM DEPICTS THE TOOL PATH AUTOMATICALLY GENERATED
BY AUTOPROMPT TO CUT A PART COMPOSED OF SPHERICAL, CYLINDRICAL, CONICAL,
TOROIDAL AND PLANE SURFACES

ROCKETDYNE

Fig. 9—2. Cutter path layout made by N/C drafting machine

The N/C working drawing is usually produced by the programmer, who uses it as a guide in identifying and sequencing the elements of the operation. In a simplified form, the N/C drawing may be made a part of the machine operator's instructions to assist him in following the machine movements, particularly during tape proving. The drawing shows the various set points and work stops that permit tool changes and operation checks.

Parameter Definition

The programmer uses a Cartesian coordinate system to define the dimensional relationships of the operation. Axis designations for various machine tools were covered in Unit 7; their application to part parameters is shown in Fig. 9-3.

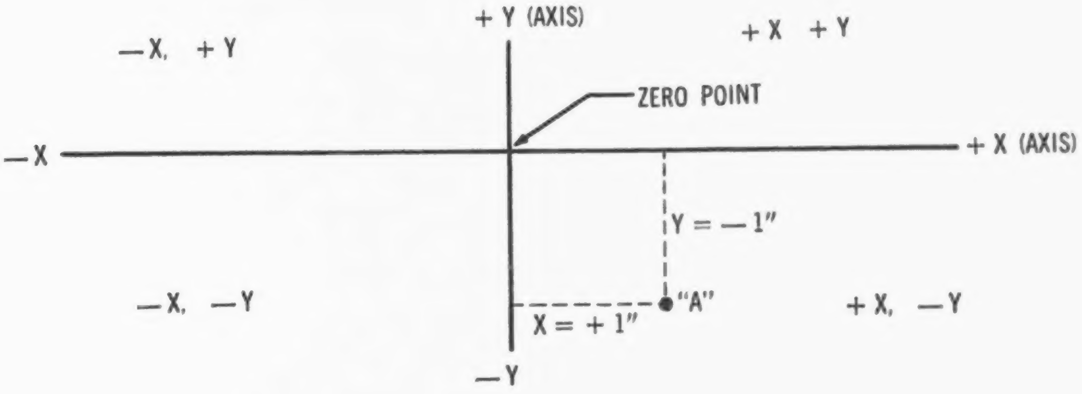


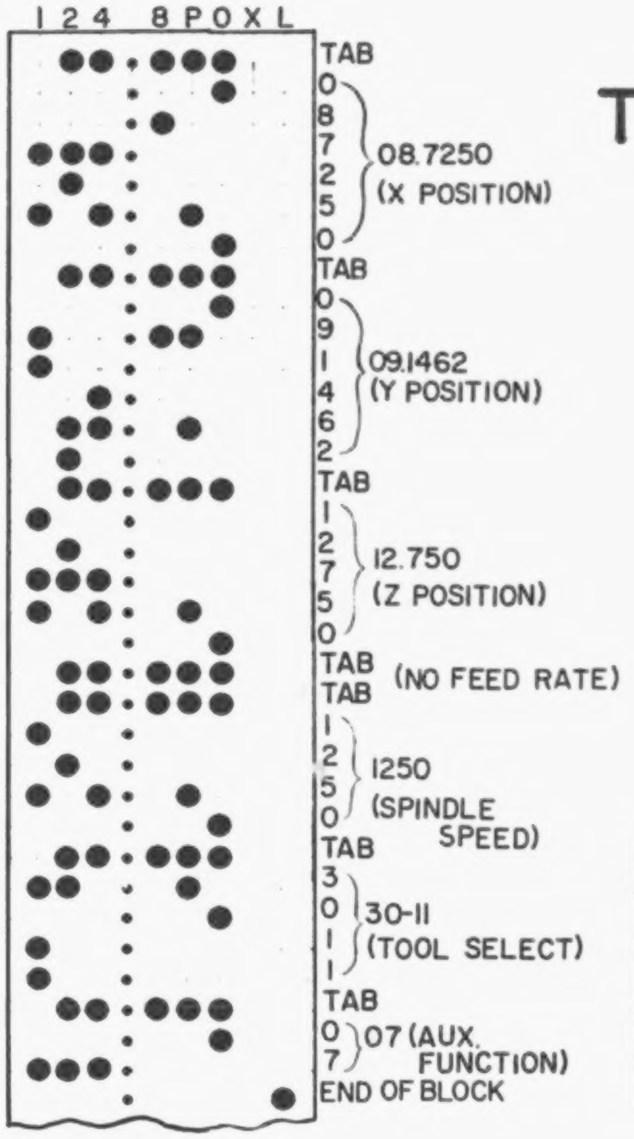
Fig. 9—3. Standard Cartesian coordinate system

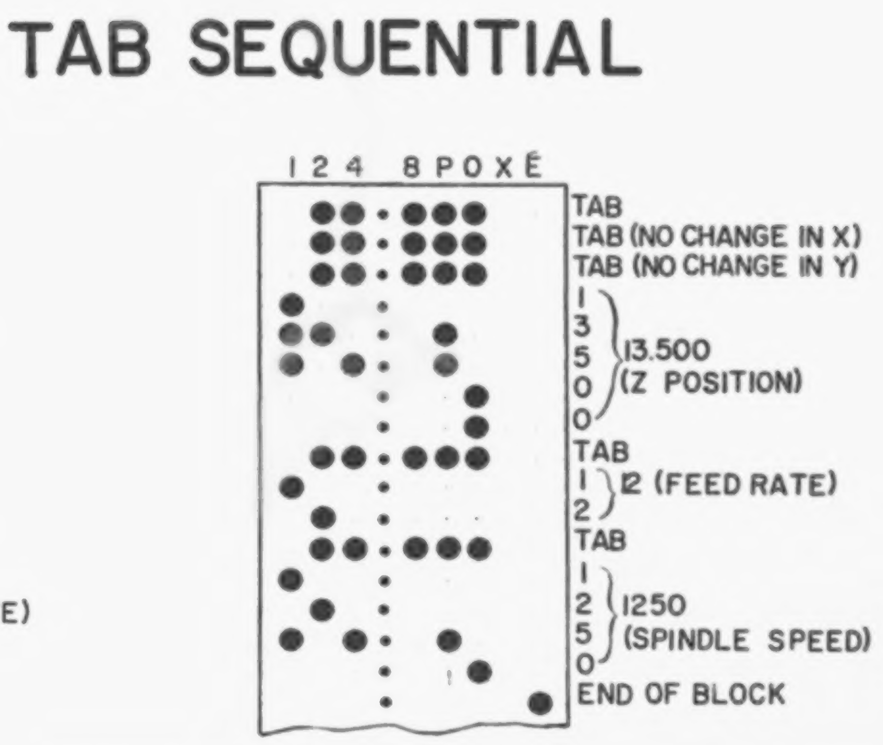
The starting point or origin may be located entirely off the part, at a corner, or at some other easily specified location. The programmer specifies the location of the origin by its x, y, and z coordinates. The initial points for motions and points for tool installation are known as set points; they may coincide with the origin or be offset from it. There is usually only one starting point, but there may be a different set point for each tool change, especially if tool changes are manual or if long table moves would be required to return to the origin. Clamp placement, clamp design, and part configuration may also restrict the selection of set points.

The programmer must visualize each motion that will result from the program he prepares. He must specify correctly the speeds, feed rates, tool length, and tool shape, while being concerned with the cutter path and with rapid traverse motions. The method of applying coolant, the selection of cutter rotation, and the application of work-locating and work-holding devices are all within the province of the programmer. A work sheet (such as the one included in Handout Sheet 9-1) designed for the specific tool and control system in use assists him to specify correctly all these variables.

Tape Preparation

After the variables have been identified and specified, the program sheet or manuscript is converted to punched cards or tape. The punching may be done by key punch, tape punch, or computer. Although the code for punching a tape (or cards) is standardized, the format in which the standard symbols are arranged is not. The programmer has a choice among several formats--fixed sequential, tab sequential, block address, and word address are the most common.


1 2 4 8 P O X L
TAB
0
8
7
2
5
0
08.7250 (X POSITION)
TAB
0
9
1
4
6
2
09.1462 (Y POSITION)
TAB
1
2
7
5
0
12.750 (Z POSITION)
TAB
TAB
(NO FEED RATE)
1
2
5
0
1250 (SPINDLE SPEED)
TAB
3
0
1
1
30-11 (TOOL SELECT)
TAB
0
7
07 (AUX. FUNCTION)
END OF BLOCK

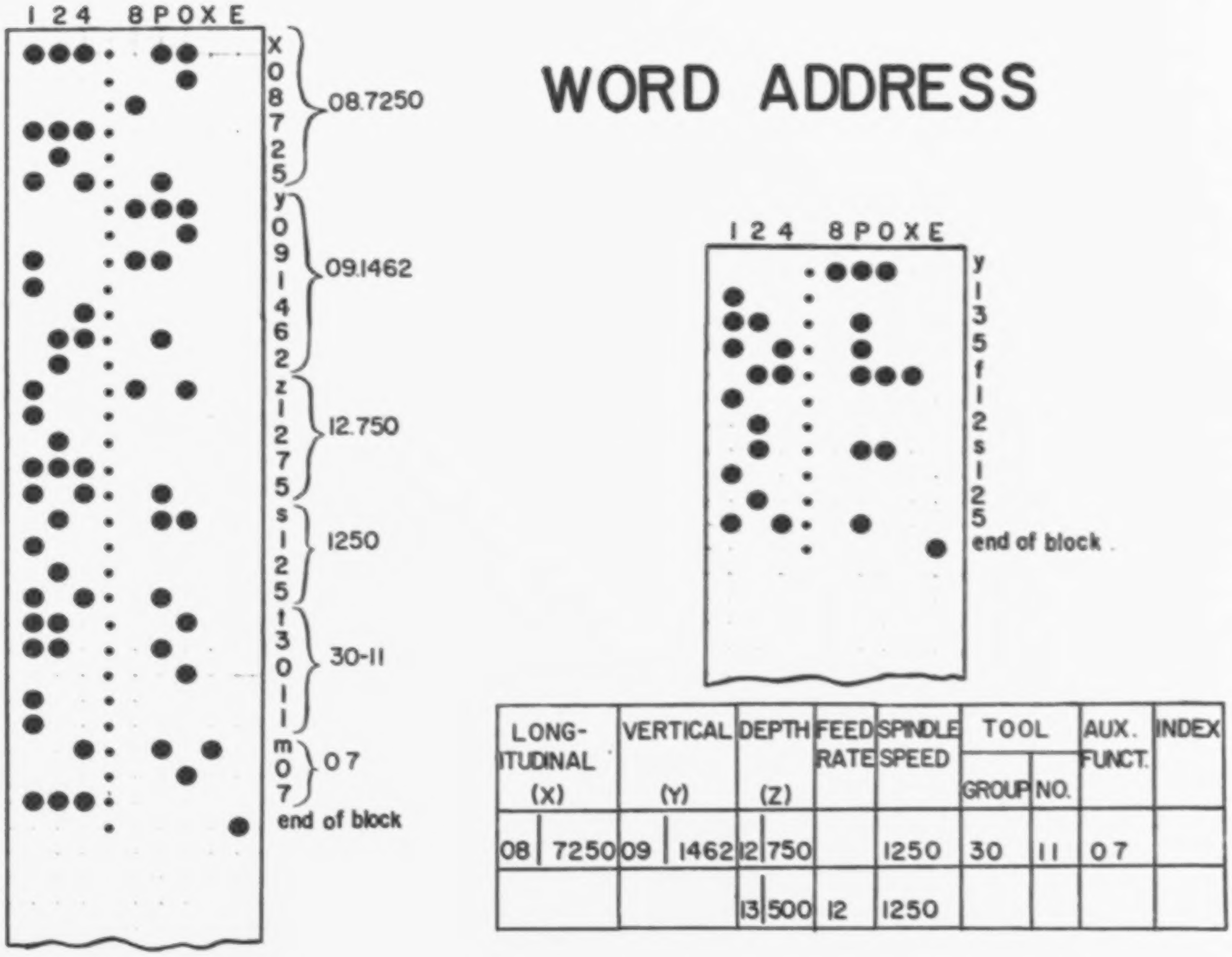

TAB SEQUENTIAL
1 2 4 8 P O X E
TAB
TAB (NO CHANGE IN X)
TAB (NO CHANGE IN Y)
1
3
5
0
0
13.500 (Z POSITION)
TAB
1
2
12 (FEED RATE)
TAB
1
2
5
0
1250 (SPINDLE SPEED)
END OF BLOCK

LONG-ITUDINAL (X)		VERTICAL (Y)		DEPTH (Z)		FEED RATE	SPINDLE SPEED	TOOL		AUX. FUNCT.	INDEX
								GROUP	NO.		
08	7250	09	1462	12	750		1250	30	11	07	
				13	500	12	1250				

Fig. 9—4. Sample tab sequential tape format

Fixed Sequential. The fixed sequential format is simplest. All variables, such as block number; x, y, and z axes; feed; speed; and coolant must be repeated in each block of information. Where incremental movements are given, zeros must be inserted to indicate no movement; where absolute dimensional relationships are called out, the position the system is to hold must be specified in each block of information. A printout looks like this:

```
0021328401570372
0032275026705521
0042275064274481
```


WORD ADDRESS
1 2 4 8 P O X E
x 0 8 7 2 5
08.7250
y 0 9 1 4 6 2
09.1462
z 1 2 7 5
12.750
s 1 2 5
1250
t 3 0 1 1
30-11
m 0 7
07
end of block
1 2 4 8 P O X E
y 1 3 5 f 1 2 s 1 2 5
end of block

LONG-ITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX
08 7250	09 1462	12 750		1250	30	11	07	
		13 500	12	1250				

Fig. 9—5. Sample word address tape format

Tab Sequential. The tab sequential format uses the same principle as fixed sequence, but permits omitting any notations which have not changed since last mentioned. Callouts are made in the same order, but repeats are tabbed over. This format requires some form of memory in the control system. A tab sequential typeout appears like this (See Figs. 9-4 and 9-5.):

```
002   13284   01570   3   7   2
003   22750   26705   5   2   1
004           64274   4   8
```

Word Address. The word address format requires that each item entered into the tape be prefixed by a symbol, usually a letter that indicates the meaning of the following number. However, only functions that are changed are entered into the tape. Their order is not specified and may suit the convenience of the programmer or the typist. A typeout looks like this:

```
002x1385y02670A3B7C1
003x22786A3B4
004y08647
```

Block Address. The block address format is a combination of word address and fixed sequential. After the block number identification code, all the functions for which change will be made are designated. Then the rows of symbols are inserted in the established sequence. The advantage of block address is that substantially fewer numbers of rows of symbols are used. Hence tape usage is reduced and reading speed increased. In some instances block address format may be read by readers primarily designed for either fixed sequential or word address formats. The typeout resembles word address without the letter insertions.

All the foregoing formats comprise blocks of information consisting of words that designate motion or nonmotion commands. Each word consists of a specific number of characters; each character is represented by one row on the tape. A word is addressed to the function it represents by a preceding symbol or by its position in the order. The term "word" is usually applied to a numerical input, which may be prefixed by a symbol specifying plus or minus. Most systems require that only negative signs be specified. Some systems, designed to operate in the positive quadrant, need no signs.

Standardized codings for most functions are contained in National Aerospace Standards Nos. 943, 945, and others. Spindle speed, table feed, dwell, start, stop, coolant, clamp, and unclamp functions are among those for which addresses and sequences have been standardized. The programmer, of course, must always know whether the system for which he is programming accepts absolute or incremental dimensional information. In general, incremental systems have wider application to operations requiring continuous path control.

Punching Equipment

The most common tape preparation equipment is the alpha-numeric type, capable of typing both alphabet and numeral symbols. The alpha-numeric tape punch works much like an electric typewriter. The tape punch can be accompanied by a tape reader, integral or auxiliary, which gives it the ability to automatically produce duplicate tapes and to make any required corrections in the process. Production of positional formats is simply accomplished by setting tabulating positions, as on a standard typewriter. In addition, some models have provision for the attachment of card-reader and card-punch units, so that tape-to-card and card-to-tape capacity is available.

A Sample Parts Program

A step-by-step review of the preparation of a sample parts program will be useful here. The job planning procedure begins with preparation of the N/C drawing; the process planner checks to ensure that all dimensions are referenced to the origin or to set points. The most advantageous sequence of operations is determined and, with dimensional data, listed on the manuscript forms. (Samples of forms used are appended to this unit as handout sheets.) The control tape is then prepared from the manuscript.

Step 1. N/C Drawing. Fig. 9-1 is a sample N/C drawing. All dimensions are located from the intersection of the x and y axes, with signs determined according to the Cartesian coordinate system shown in Fig. 9-3. The drawing is for a system using absolute positioning. A drawing for an incremental control system would show distance and direction of each motion rather than coordinates of the destination point.

The starting point is located by the planner at any desired position on the work or adjacent to it. He keeps in mind the value of easy calculation of the dimensions of other key points, such as hole locations, from the starting point. The planner next establishes the required set point or points at locations that will be convenient for the machine operator. The origin and a set point need not coincide. The first blocks of information on the tape will contain the coordinates of starting point and set point. This information will be used by the machine operator for setup, as prescribed in the manual for the specific tool.

Step 2. Sequence of Operations. With the starting point determined, the location of each of the remaining holes or operations to be completed is examined; and the most economical order of performance, with respect to dimensional relationships and required tool changes, is determined. The planner places a sequence number on the N/C drawing at each point where work is to be performed and notes the coordinates of each.

Step 3. Manuscript Preparation. A detailed treatment of manuscript preparation will be given in Unit 10. The planner must be careful to use the manuscript format that is suitable for the tape preparation equipment and for the characteristics of the machine control system.

Step 4. Specification of Miscellaneous Functions. The programmer must visualize all of the auxiliary operations that will be required to make the total operation as self-sufficient as possible. He must provide for "tape rewind" and "rewind stop" signals on the tape. Where automatic tool change will occur, he must ensure that there will be sufficient clearance at the location for the changing action. If tool change is manual, the tool change specification on the tape provides for the logic function to stop and usually for a signal at the control console. When the change has been completed, the operator presses a restart button to restore the logic function. Two miscellaneous functions that can be used in combination are tape rewind and tool change, i. e., rewinding can be accomplished during a tool change stop. A "stop rewind" code may be placed on the tape after the data that locates the origin and the first setup point, if these two points are used for setup of the first piece only and are not used on succeeding pieces.

Step 5. Tape Punching. The actual punching of the tape is the final step in the preparation of an N/C program. Careful examination of the sample manuscripts provided (Handout Sheet 9-1) will show that each successive sample gives information of increasing complexity. The three sheets were drafted for three different tape preparation units, similar but with different degrees of variability. The "Tab" columns indicate that the carriage of the puncher must be tabbed to the next column of information. The "EOB" (end of block) notation indicates the carriage shifts to a new line of information. The plus or minus designation indicates direction of each move; usually only a minus need be indicated. Each of the axis columns provides space for the coordinate to be written. And the programmer's manual for the system will specify the number of decimal points in the notation.

A separate operator's instruction sheet is not usually prepared when instruction columns are provided on the manuscript. These instructions are not normally coded into the tape, but when they are coded, restrictive symbols may be used so that those not pertinent to the N/C operation will be ignored by the tape reader at the machine.

Some positioning systems, such as the Pratt & Whitney Tape-O-Matic have available as many as three kinds of tape preparation equipment. One form provides for setting a series of dials to encode an entire block of information at a time. No printout is available. Another uses a ten-key input similar to that of an adding machine, with no provision for alphabet input except certain function codes. This second type of punch has printout capability and can be used to verify and to duplicate tapes.

However, the most flexible tape punch unit is one with an alpha-numeric keyboard. Complete instruction sheets can be prepared as duplicate tapes are run, and full verification of a tape is possible. There are several models of this type punch, available with auxiliary card and tape readers and punching units. On at least one model the printout is on the tape itself; on others, computer functions can be simulated for instructional purposes.

INSTRUCTIONAL TECHNIQUES

References

Milwaukee-Matic Part Processing Manual. Kearney & Trecker Co.
Programmer's Manuals. Burgmaster Corp.
Programmer's Manual for #3 Cintimatic. Cincinnati Milling Machine Co.
Tape-O-Matic Operator's and Programming Instruction Manual. Pratt & Whitney Corp.

Handout Materials

Sample programming manuscript form (Handout Sheet 9-1)

Audio-Visual Materials

Numerically Controlled Drill. Sound, color film, 15 min. Produced by Pratt & Whitney Corp. Available through Germaine-Moore Machinery Co., Los Angeles, Calif.
Months to Minutes (Milwaukee-Matic II). 16 mm. color, sound film, 20 min. Produced by Kearney & Trecker Co. Available through Germaine-Moore Machinery Co., Los Angeles, Calif.
Machine It For Less (Cintimatic Drill). Film produced by Cincinnati Milling Co. Available through Tornquist Machine Co., Los Angeles, Calif.

Instructor Activities

1. Prepare conventional fabrication outlines and route sheets for completion by students prior to implementing N/C problems.
2. Prepare transparencies of N/C drawings and manuscript formats for class use in development of principles and basic concepts.
3. Design problems around part drawings and available N/C equipment. Use completed parts and representative tooling to suggest alternatives.

Student Activities

1. Complete route sheets for conventional operations.
2. Solve problems as assigned.
3. Analyze part programs for effects of machine motions; correct errors noted.
4. Analyze tape samples to determine effects of machine motions; prepare manuscript corrections for errors noted.

5. Compare various formats with respect to control system needs and punching equipment requirements.
6. Analyze part drawings to determine operation sequences. Sketch and label N/C drawings, using correct notations.
7. Prepare a control tape and a correct typeout.

Handout Sheet No. 9-1

SAMPLE PROGRAMMING MANUSCRIPT (p. 1 of 3)

PROCESS CHART FOR P & W TAPE-O-MATIC

PRATT & WHITNEY INC

WEST HARTFORD, CONNECTICUT, U.S.A.

DWG. NO. C-10109

PART NO. DOO-1312

OPER NO. 4

PART NAME Figment Plate

PREPARED BY

DATE

CH'D. BY

DATE

SHEET OF

DEPT. NO.

PART NO.

LATEST DWG. CHGE.

REMARKS: Sample process for ultra-sonic "Tape-Master" tape punch

MODE FUNC	SEQ NO.	TAB OR EOB	+ OR -	X COORDINATE	TAB OR EOB	+ OR -	Y COORDINATE	TAB OR EOB	M FUNC	TAB OR EOB	INSTRUCTIONS	EOB
	000	TAB	-	04.500	TAB	+	00.875	EOB			Set-up information	
	001	TAB	-	03.500	TAB	+	00.000	EOB			Set depth and center drill 6 holes	
	002	TAB	-	00.500	TAB	+	00.000	EOB				
	003	TAB	+	00.500	TAB	-	00.250	EOB				
	004	TAB	+	00.000	TAB	-	02.781	EOB				
	005	TAB	+	00.000	TAB	-	04.531	EOB				
	006	TAB	-	03.031	TAB	-	04.000	EOB				
TC	007	TAB	+	03.500	TAB	-	03.000	EOB			Change tool to comb. drill & c'bore	
	002	TAB	-	00.500	TAB	+	00.000	EOB			Drill and c'bore 2 holes 19/32 x 5/16	
	004	TAB	+	00.000	TAB	-	02.781	EOB				
TC	007	TAB	+	03.500	TAB	-	03.000	EOB			Change tool to comb. drill & c'bore	
	001	TAB	-	03.500	TAB	+	00.000	EOB			Drill and c'bore 4 holes ___ x ___	
	003	TAB	+	00.500	TAB	-	00.250	EOB				
	005	TAB	-	00.000	TAB	-	04.531	EOB				
	006	TAB	-	03.031	TAB	-	04.000	EOB				
TC RW	007	TAB	+	03.500	TAB	-	03.000	EOB			Change tool to center. Unload and replace part.	

Note:

RWS is used to indicate tape rewind stop

TC is used to indicate tool change

RW is used to indicate tape rewind

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Handout Sheet No. 9-1

SAMPLE PROGRAMMING MANUSCRIPT (continued)

PROCESS CHART FOR P & W TAPE-O-MATIC

PRATT & WHITNEY INC

WEST HARTFORD, CONNECTICUT, U.S.A.

DWG. NO. C-10109
PART NO. DOO-1312

OPER NO. 4

PART NAME Figment Plate

PREPARED BY
DATE
CH'D. BY
DATE
SHEET OF
DEPT. NO.
TAPE NO.

LATEST DWG. CHGE.

REMARKS:

MISC FUNC	SEQ. NO.	TAB OR EOB	+ OR -	"X" COORDINATE	TAB OR EOB	+ OR -	"Y" COORDINATE	TAB OR EOB	M FUNC	TAB OR EOB	INSTRUCTIONS	EOB
		TAB	-	4.500	TAB	+	.875	EOB			Setup information	
	001	TAB	-	3.500	TAB		0	EOB			Set depth and center drill 6 holes	
											two 5/16 dia. and four 1/4 dia.	
	002	TAB	-	.500	EOB							
	003	TAB	+	.500	TAB	-	.250	EOB				
	004	TAB		0	TAB	-	2.781	EOB				
	005	TAB			TAB	-	4.531	EOB				
	006	TAB	-	3.031	TAB	-	4.000	EOB				
TC	007	TAB	+	3.500	TAB	-	3.000	EOB			Change tool to comb. drill and c'bore	
											___ c'bore and ___ drill	
	002	TAB	-	.500	TAB		0	EOB			Drill & c'bore 2 holes 17/32 x	
											5/16	
	004	TAB		0	TAB	-	2.781	EOB				
TC	007	TAB	+	3.500	TAB	-	3.000	EOB			Change tool to comb. drill & c'bore	
											___ c'bore and ___ drill.	
	001	TAB	-	3.500	TAB		0	EOB			Drill and c'bore 4 holes	
											15/32 x 1/4	
	003	TAB	+	.500	TAB	-	.250	EOB				
	005	TAB		0	TAB	-	4.531	EOB				
	006	TAB	-	3.031	TAB	-	4.000	EOB				
TERM	007	TAB	+	3.500	TAB	-	3.000	EOB			Change tool to center drill	
											Remove and replace part	

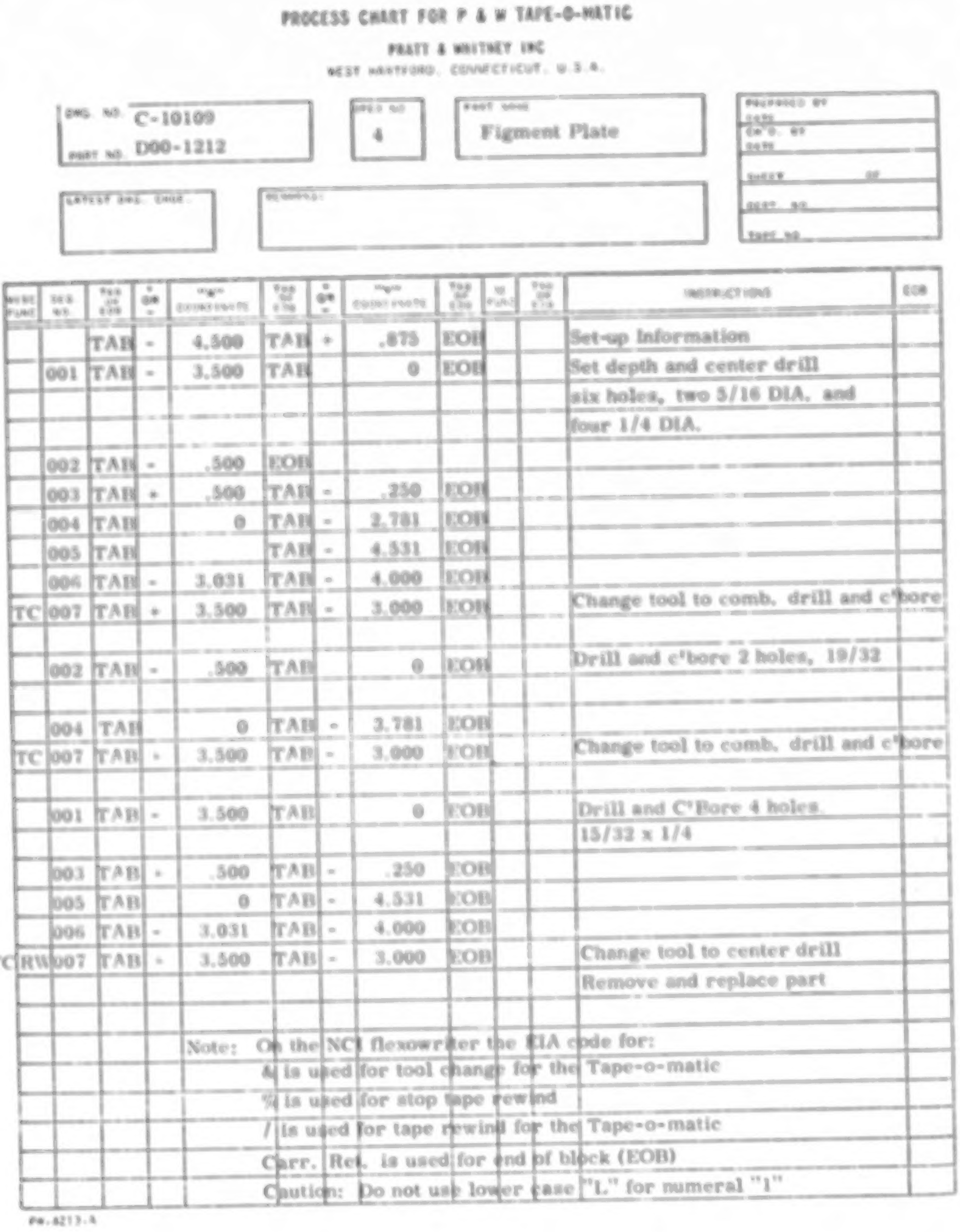
Note: On the NC1 flexowriter the EIA code for:

& is used for tool change for the Tape-o-matic
% is used for stop tape rewind
/ is used for tape rewind for the Tape-o-matic
Carr. Ret. is used for end of block (EOB)
Caution: Do not use lower case "L" for numeral "1"

PW-6213-4

Handout Sheet No. 9-1

SAMPLE PROGRAMMING MANUSCRIPT (continued)



PROCESS CHART FOR P & W TAPE-O-MATIC

PRATT & WHITNEY INC
WEST HARTFORD, CONNECTICUT, U.S.A.

DWG. NO. C-10109
PART NO. D00-1212
OPER NO. 4
PART NAME Figment Plate
PREPARED BY
DATE
CH'D. BY
DATE
SHEET OF
DEPT. NO.
TAPE NO.
LATEST DWG. CHGE.
REMARKS:

MISC FUNC	SEQ NO.	TAB OR EOB	+ OR -	X COORDINATE	TAB OR EOB	+ OR -	Y COORDINATE	TAB OR EOB	M FUNC	TAB OR EOB	INSTRUCTIONS	EOB
		TAB	-	4.500	TAB	+	.875	EOB			Set-up Information	
	001	TAB	-	3.500	TAB		0	EOB			Set depth and center drill	
											six holes, two 5/16 DIA. and	
											four 1/4 DIA.	
	002	TAB	-	.500	EOB							
	003	TAB	+	.500	TAB	-	.250	EOB				
	004	TAB		0	TAB	-	2.781	EOB				
	005	TAB			TAB	-	4.531	EOB				
	006	TAB	-	3.031	TAB	-	4.000	EOB				
TC	007	TAB	+	3.500	TAB	-	3.000	EOB			Change tool to comb. drill and c'bore	
	002	TAB	-	.500	TAB		0	EOB			Drill and c'bore 2 holes, 19/32	
	004	TAB		0	TAB	-	3.781	EOB				
TC	007	TAB	+	3.500	TAB	-	3.000	EOB			Change tool to comb. drill and c'bore	
	001	TAB	-	3.500	TAB		0	EOB			Drill and C'Bore 4 holes.	
											15/32 x 1/4	
	003	TAB	+	.500	TAB	-	.250	EOB				
	005	TAB		0	TAB	-	4.531	EOB				
	006	TAB	-	3.031	TAB	-	4.000	EOB				
TC RW	007	TAB	+	3.500	TAB	-	3.000	EOB			Change tool to center drill	
											Remove and replace part	
				Note: On the NCI flexowriter the EIA code for:								
					& is used for tool change for the Tape-o-matic							
					% is used for stop tape rewind							
					/ is used for tape rewind for the Tape-o-matic							
					Carr. Ret. is used for end of block (EOB)							
					Caution: Do not use lower case "L." for numeral "1"							

PW-6213-A

unit 10
MANUSCRIPT PREPARATION

PLAN OF INSTRUCTION

Objectives

- To acquaint the student with the techniques of communication and the procedures necessary to the development of a parts program
- To instill in students the understanding of the need for using correct machining techniques and tool callout to achieve economical utilization of N/C
- To identify skill requirements and develop student understanding of the visualization, organization, and writing that are essential to parts programming for positioning control systems
- To provide the student experience in basic geometric identification, using N/C drawings, identification, and callouts in manuscript preparation

Introduction

1. Discuss a sample manuscript, an N/C drawing, and a parts drawing, identifying key features and concepts.
2. Detail the procedure for determination of operation sequences.

Presentation

1. Review the requirements and techniques of point identification.
2. Discuss determination of tool-use sequences and function coding.
3. Elaborate on the determination of machining sequences.
4. Describe manuscript formats, relating them to control system requirements and to machine tool configurations.
5. Discuss tooling location and parts positioning.
6. Review callout of speed, feed, and auxiliary functions.
7. Relate machine motion callout to control system variables and to manuscript format.
8. Investigate manuscript preparation problems in connection with workholding and tool-motion variables.

RESOURCE UNIT

Parts programming is a refinement of the planning process in the light of higher production capability. And N/C job planning can be performed by machinists and machine operators as well as by methods planners. The activities of any parts programmer are directed toward greater efficiency and improved precision. Numerical control of machine tools, of which programming is an integral part, gives a more effective method of converting a blueprint into finished parts.

Kinds of Programming

A control tape can be prepared by any one of three approaches. One is more or less mechanical; dials are set, or the machine is moved, and a record is thereby produced. In a second approach, an organized work sheet is developed and translated into a control tape by a key-actuated punch mechanism. This second method is referred to as manual programming. The third approach is the preparation of a tape with the aid of a computer.

Computer-assisted programming shows the greatest promise for long-range application, but manual programming is more applicable to the teaching process and is more immediately available. Manual programming is far from obsolete in the dynamically expanding technology of N/C. Rather, it is an effective technique and a sound basis from which to progress to more complex techniques. Manual programming is extremely useful to the small shop operation and is applicable as well to situations in conjunction with computer-aided programming that involve error analysis, engineering change, and the like.

Complex operations involving continuous path control or calculation and recalculation with intricate formulas can usually be accomplished more effectively with computer-assisted programming. Many positioning systems today have milling capability, which requires positive feed control between programmed points. Since a curve is simply a series of straight lines, the application of a computer makes it possible to program a less-sophisticated positioning system to perform contouring operations, with only a small loss in efficiency and an increased volume of tape required.

Manuscript Preparation

The preparation of a program and the production of the tape for any of the systems of control depend directly upon a careful analysis of the machining problem and a diagram of the procedure. With conventional equipment the skill of the planner and the machinist were perhaps equally involved. The preparation of an N/C manuscript involves a greater degree of preplanning, for the manuscript content must be related to the specific tool, its control system, and the complexity of the part to be produced. Standardization of functions and coding has done much to simplify programming, even though program requirements have been increasing steadily. Specialized programming languages, which will be taken up in Unit 11 following, have provided still more efficiency to the programming operation.

The differences between available control systems make it imperative to study the manufacturer's operation and programming manual(s) for a machine before attempting to prepare a program for it. The manuscript can then be prepared on an appropriate form following the specific rules for each machine and control unit combination. Transferring blueprint information to the planning sheet involves more than familiarity with machine shop practices; ingenuity in planning, correct selection of tools and fixtures, and efficient application of machining techniques must be included in the manuscript in the language of N/C.

Manuscript Format

The characteristics of the machine tool, the control system, and the tape punching unit all affect the items which must be included in the manuscript. As previously noted, all systems use Cartesian coordinates. However, some utilize motion commands in terms of an absolute scale from a fixed origin, while others use incremental positioning, or the distance and direction from the last position. And in either case, the zero position can be fixed or floating. The form this zero point takes governs the manner in which the manuscript is prepared, just as it governs the technique of setting up and locating the tooling.

While a student is being introduced to the operating potentials and techniques of N/C, he should also be given experience with the factors involved in preparing a simple manuscript. To begin, the fundamental headings normally included in any manuscript are shown in Fig. 10-1.

Sequence #	Prep Function	x position	y position	T	Misc. function

Fig. 10—1. Sample of form for N/C manuscript

The Sequence Number identifies each block of information, in much the same way as an operation number is used in conventional route sheets. "Preparatory

Function" gives such functions as the kind of machining cycle to be performed. The specific codes used here vary from machine to machine; however, essential guidelines are contained in NAS 943 and NAS 955. Preparatory functions, commonly called "G" functions, are written G78 or g78; their numbers usually are selected from 60 through 89. Examples of such functions include mill cycle, mill cycle stop, cancel cycle, drill cycle, tap cycle, and bore cycle (with feed both in and out).

The x and y position columns, with a z column when 3-axis control is used, are for the coordinate dimensions. In present practice the manufacturer specifies the number of decimal places to be used for each position designation. The decimal points are neither written nor punched into the tape. Thus, on a format specifying five digits with three decimal places, a coordinate of 10.375 inches would appear as simply 10375. If six digits and four decimals were called for, the same coordinate would be written 103750. Where spindle travel is less than 10 inches, the z position column may specify one less digit than the others.

The T column identifies the tool to be used. In earlier formats tool information was placed in a general information or description column; the separate column has proved very convenient. The tool code may be selected from preset tooling codes established for a company or may show the turret number in which the tool is mounted.

The "Miscellaneous Function" column provides space for entering the "M" functions such as program stop (to permit part measurement or tool change), end of program, or change of depth cam (for z axis travel). RPM and feed rate settings may be specified in this column.

Not all depth or z axis motions are programmed in the same manner. For some machine tools, the distances are programmed from the table up as a plus distance; for others, from a set point in space as plus toward the table. Each has certain advantages from programming and operation standpoints.

Where the manuscript is also used to provide operator instructions, these are entered in the "instruction" column. They would include such items as setup instructions for both fixtures and cutting tools.

Fig. 10-2 illustrates another manuscript format. Note that "plus or minus" columns are provided before each coordinate position column. Tab or EOB (end of block) columns are also used. The form is tailored to the characteristics of the machine tool and its control system and to the tape-punching equipment to be used.

Misc. function	Seq. #	Tab or EOB	+ or -	X coordinate	Tab or EOB	+ or -	Y coordinate	Tab or EOB	Instructions

Fig. 10—2. Sample manuscript format

Programming Sequence for a Turret Drill

The steps in preparing a simple program for a turret drill operation are outlined and illustrated in the following material as a sample of programming sequence. The general conditions and general rules are:

- The machine uses an absolute positioning system with a fixed zero at the left rear corner of the positioning table.
- The fixtures and parts can be located exactly with reference to the zero point.
- All hole locations are calculated with reference to a set point, which is related to the zero point.
- Z axis or spindle motion, although automatically actuated, requires a manual depth setting, to be indicated in the general information section of the manuscript.
- X axis is left and right; Y axis is perpendicular to the X-Z plane.
- X and Y coordinates require use of five digits, to three decimal places.
- All G and M codes should be defined as they are designated.
- Tooling code consists of the turret position selected for the tool mounting.

Step 1. The first step is to prepare an N/C drawing in sketch form, on a form such as illustrated in Fig. 10-3. On the drawing the zero point, set points, clamp positions, and hole sequence are identified. Where a subplate setup is designated, the subplate tooling number is indicated, together with the number of studs, clamps, washers, and other clamping materials to be furnished. Pertinent setup information for the machine, control, or job is specified.

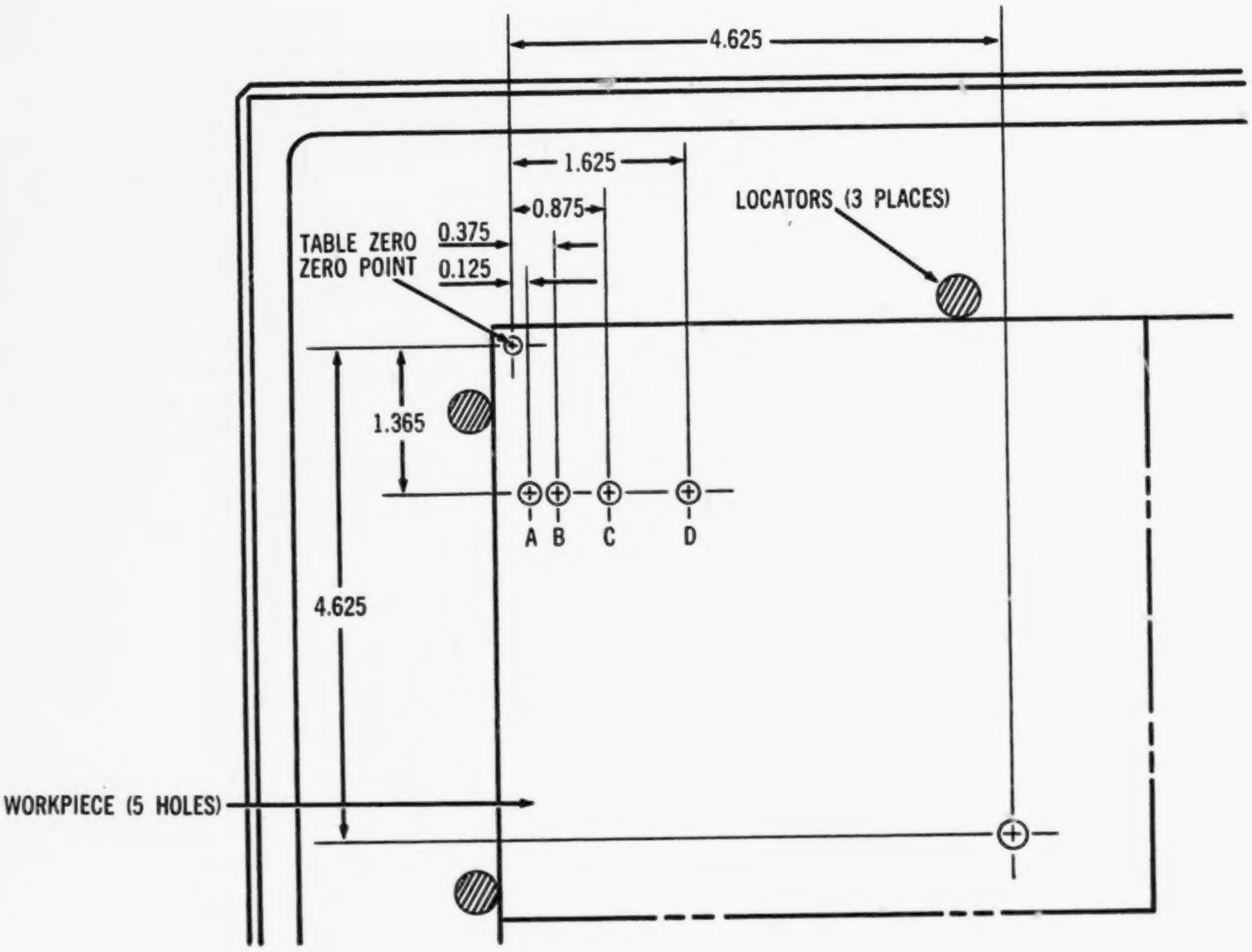


Fig. 10—3. Sample N/C drawing

Step 2. The exact dimensions of the part in each axis are determined and referenced to the zero point and the set point or points. The coordinates of each hole are listed on the N/C drawing.

Step 3. Identification numbers are assigned to each hole, or other item to be machined, and entered on the N/C drawing. A satisfactory procedure is to assign the same letter, accompanied by a sequential number, to all holes of the same size. Thus, a group of holes of identical size might be identified as C1, C2, C3, or as 1C, 2C, 3C. Holes of a different size would be labeled B1, B2, and so on.

Step 4. The logical machining sequence is next determined. For instance-- all holes of like diameter should be center drilled, then drilled, bored, reamed, and tapped, or whatever the required operations are. When those are completed, a second set of operations is programmed. The rapid traverse rates are not always the same for all axes, and they do not always function without a special signal. On small machines, rapid traverse rates are usually about 3 to 4 inches per second. Spindle rates are at higher limits, and the spindles have shorter distances to move. Tool change takes one or more seconds. With these factors in mind, consideration must always be given to completing all applications of a given cutting tool, by moving the table, rather than completing each hole in order before moving to the next. The choice may fall to completing each hole if there are three or more operations at each hole, if exceptionally accurate hole sizes must be maintained, or if the holes are scattered over a wide area.

Step 5. When the sequence has been determined, the manuscript is filled in one line at a time, with the functions and coordinates entered as determined. As each line is completed, the speed and feed rates should be verified, as well as the tool clearances.

Step 6. A check is then made to verify consistency of absolute or incremental programming, fixed or shifting zero position, and the tape format address and sequence requirements.

Step 7. The tape is punched, and the typeout is proofread.

Potential Difficulties

No errors whatsoever can be tolerated in the tape. Punctuation, word forms, and address forms must be absolutely correct. If five rows in the tape are required to produce a specific word and only four rows are used, the reader normally will stop and no action will result. The use of an incorrect letter in a letter-number combination, as in the word address format, will either stop the reader or cause a wrong function that may damage a tool or a part. If the control system does not include a memory, then dimension, motion and function instructions must be repeated on each line of the manuscript and punched into the tape accordingly. If the control system includes a memory, as is the case with most absolute positioning systems that use address coding, information that does not change need not be repeated. New instructions are inserted only when they are required to stop or to change an action.

This repetition requirement can be illustrated by the programming of the part shown in Fig. 10-3. The program is for an absolute positioning system with both address coding and a memory. The first hole is located at x = 0.125 and y = 1.365. Therefore, the program for the center of that hole would be x 00125 y 01365. The y dimension does not change for the second, third, and fourth holes, but does change for the fifth. The y dimension will be retained by the memory and used until changed. The location portion of the typeout appears like this:

x 00125	y 01365
x 00375	
x 00875	
x 01625	
x 02625	y 04625

If the programmer decided not to use the memory feature, the program would be entered thus:

x 00125	y 01365
x 00375	y 01365
x 00875	y 01365
x 01625	y 01365
x 02625	y 04625

The programmer's decision will be guided by the fact that unnecessary repetition of the y coordinate will increase the control tape length (nearly two inches in this case) and will increase the chance of errors in writing or interpreting the manuscript, in producing the tape, and in reading the tape by the control reader.

Proper use of the memory feature will result in a shorter tape. Speed and feed information, tool coding, and other instructions need not be repeated. And in some systems the coordinate dimension callouts need only contain the digits that are changed in each block of information.

Miscellaneous functions generally have an address letter assigned. These are accepted by the tape reader, and the function will be activated in the manner specified at the time required. Miscellaneous functions are entered in the space provided on the manuscript; on the tape they can be included in the same block with position information, since their sequence in the block does not affect acceptance and use by the control.

A Sample Manuscript

A sample manuscript can be written, based on the principles covered thus far, for the part illustrated in Fig. 10-4. Hole A is to be drilled and bored to 3/8 inch diameter; hole B is to be drilled and reamed to 5/8 inch diameter, and hole C requires a 1/2 inch--13 tap.

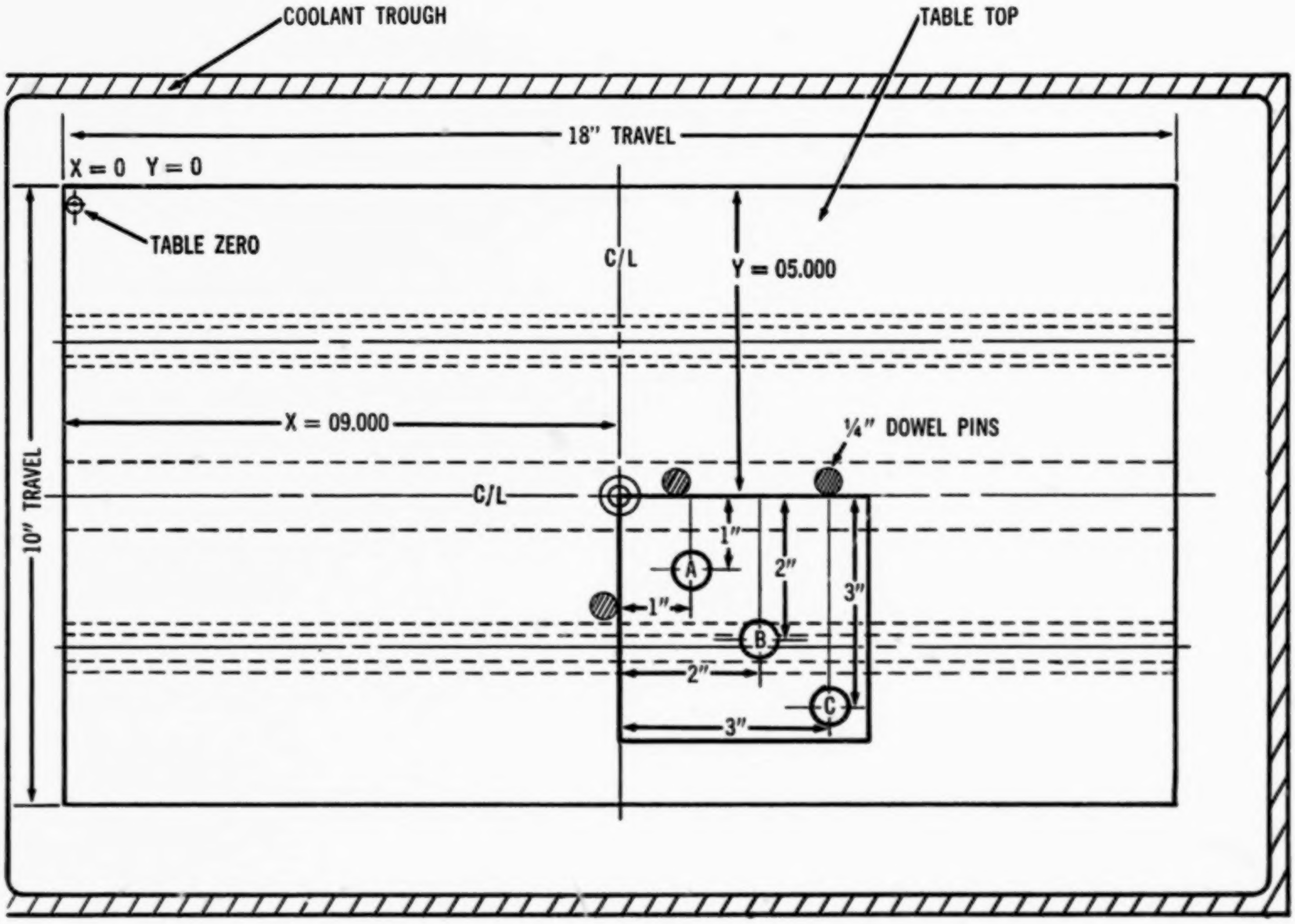

COOLANT TROUGH
TABLE TOP
18" TRAVEL
X = 0 Y = 0
TABLE ZERO
C/L
Y = 05.000
X = 09.000
¼" DOWEL PINS
C/L
10" TRAVEL
1"
2"
3"
A
B
C
1"
2"
3"

Fig. 10—4. Sample N/C drawing of part on machine table

The programmer decides to set up tools as follows:

Spindle 1	Drill, 23/64"
Spindle 2	Drill, 39/64"
Spindle 3	Tap, 1/2"
Spindle 4	Boring bar, 0.375" diam.
Spindle 5	Drill, 27/64"
Spindle 6	Reamer, 5/8"

The spindle choices here are arbitrary, but in practice might be controlled by special provisions of the machine for specific spindles, such as different speed ranges or tooling features.

Next, the speed and feed rates are established and entered in the program, and the tools are related to the hole codes selected. The order of operations is established and recorded on the form. Preparatory and miscellaneous functions required are determined. The lines are filled in with the appropriate sequence numbers assigned, and the program checked.

For this illustrative program, the A hole was selected to be drilled first. Coordinates are determined to be x 10.000 and y 06.000. The drill required for this operation has been designated for spindle 1; since coolant is required, function code M08 is specified. The preparatory function for a drilling cycle has been given code G81; this is entered in the manuscript.

On the second line the next hole to be drilled is listed, and so on. The entire program is illustrated in Fig. 10-5. Following the program through, the observer will note that each hole is drilled with the appropriate drill; without moving the table, hole B was reamed. At the end of the reaming operation, the coolant is shut off, so that the next hole can be bored to size. The coolant is turned back on for the tapping sequence, and again shut off. The final miscellaneous callout, M02, indicates the end of the program or cycle.

The samples of manual program given here are quite simple. Needless to say, the planning procedure for more complicated parts can be extremely complex. Manual programming is of great value when considered by instructor and student as an intermediate step in training, as well as an interim tool to use in preparing control tapes. Certainly, facility with manual programming for N/C will make it easier to understand and become proficient in computer-assisted programming techniques involving such languages as ADAPT, AUTO SPOT, and AUTO PROMPT; the application of postprocesses; and other devices and procedures that are included in advanced training programs.

NUMERICAL CONTROL PROGRAM SHEET FOR 2-AXIS CONTROL

Drawing no.	Piece no.	Part name	SH. NO. OF
Fixture no.	Checked by	Fixture location Section: Bin:	Planning date

Machine no.

Spindle No.	Operation		Holes	Spindle rpm	Spindle feed ipm
1	23/64 Drill		A	1000	7
2	39/64 Drill		B	700	8.4
3	1/2-13 Tap		C	225	17.3
4	Bore .375 diameter		A	1000	3
5	27/64 Drill		C	1000	7
6	Ream 5/8 diameter		B	450	6.7

Seq. no.	Prep funct.	X-Dimension	Y-Dimension	Tool no.	Misc. funct.
001	G81	10000	06000	1	Mo8
		10000	06000	1	Mo8
002	G81	11000	07000	2	
		11000	07000	2	
003	G81	12000	08000	5	
		12000	08000	5	
004	G83			6	Mo9
				6	Mo9
005	G82	10000	06000	4	Mo8
		10000	06000	4	Mo8
006	G84	11000	07000	3	
		11000	07000	3	Mo9
007					Mo2
					Mo2

Fig. 10—5. Sample completed N/C program sheet

INSTRUCTIONAL TECHNIQUES

References

National Aerospace Standards No. 943 and 945. Washington: Aerospace Industries Association of America, Inc., 1963.

Numerical Control for Metalworking Manufacturing. Edited by Burnham Finney. New York: McGraw-Hill Book Co., 1960.

Numerical Control Today. Edited by J. W. Greve. Detroit: American Society of Tool and Manufacturing Engineers, 1960.

Handout Materials

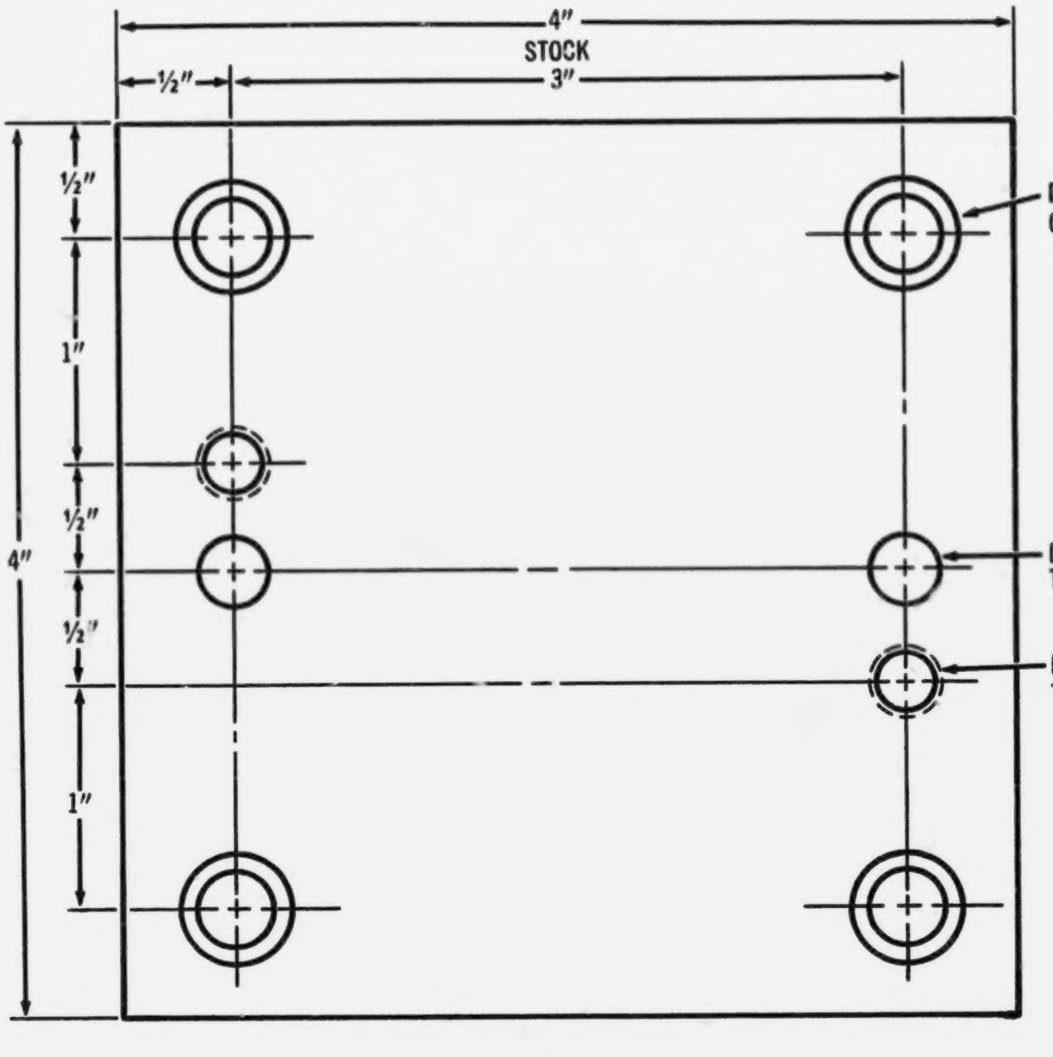
Copies of Figs. 10-3, 10-4, and 10-5
Sample Part Drawing (Handout Sheet No. 10-1)
Sample Program Forms (Handout Sheets No. 10-2 and 10-3)

Student Activities

1. Prepare a complete program manuscript for the part shown in Handout Sheet No. 10-1. Use organization format for a single spindle drill press, manual tool change, and incremental positioning from a zero fixed in the center of the machine table.
2. Prepare a complete manuscript as above for the same machine equipped with absolute positioning and a floating zero.
3. Prepare a complete program manuscript for the part shown in Handout Sheet No. 10-1. Use organization format for a 6-spindle turret drill that has a fixed zero in the rear lefthand side of the table, absolute positioning, and memory capability in the control system.
4. Prepare a complete program manuscript for the same part and a similar machine that is equipped for a floating zero and incremental positioning, and that has two parts mounted on the table to be run alternately.
5. Make a design sketch for the holding tool that would be used in the first three cases above. Suggest differences that would be necessary for each installation.
6. Describe efficiencies in operation that can be realized with each of these organizational concepts.
7. Discuss the efficiency potentials for each of the above tools when applied to manufacture of parts of the type illustrated in Handout Sheet No. 10-1.

Handout Sheet No. 10-1

SAMPLE PART DRAWING



DRILL 11/32" DIA. THRU 4 PLACES
C'BORE ½" DIA. 11/32" DEEP

DRILL AND REAM 5/16" DIA. S. F.
THRU 2 PLACES

DRILL "F" (00.257) DIA. THRU AND
TAP 5/16—18 N. C.—2 PLACES

Handout Sheet No. 10-2

SAMPLE PROGRAM FORM

BP #

OPERATION NC #

PART NAME AND NUMBER

POS. NO.	X POSITION	Y POSITION

Handout Sheet No. 10-3

SAMPLE PROGRAM FORM

PROGRAM FOR 3 CINTIMATIC

CINCINNATI
ACRAMATIC POSITIONING
NUMERICAL CONTROL SYSTEM

PART NAME
PART NO.
DRAWING NO.
REVISION
FIXTURE NO.
PROGRAMMED BY
PAGE OF PAGES
SET UP AND TOOL INFORMATION
DATE

H or N	G	X	Y	M								
SEQ. NO.	PREP. FUNCT.	POSITION	POSITION	MISC. FUNCT.	POS. NO.	TOOL NO.	HEAD POS.	SPINDLE FEED IN. MIN.	SPEED RPM	DEPTH OF CUT	TABLE FEED IN./MIN.	TOOL REMARKS

unit 11

ADAPT AND THE COMPUTER

PLAN OF INSTRUCTION

Objectives

- To introduce the student to computer-assisted parts programming
- To develop the student's ability to understand simple programs in ADAPT language
- To develop appreciation of the computer as a tool in N/C manufacturing technology

Introduction

1. Discuss manual performance of the calculations needed to accurately control a cutter path to produce a circle.
2. Describe the function of ADAPT language, emphasizing its English-like qualities and compatibility with APT.

Presentation

1. Describe the development of the computer as a problem-solving device.
2. Explain the Parsons Corp. system for defining tool and parts relationships in terms of jig borer coordinates by computer routines.
3. Review the development of APT, defining the proprietary aspect of the language.
4. Review the development and application of ADAPT.
5. Show ADAPT methods of point, line, and circle definition.
6. Illustrate correct terms for starting and stopping motion.
7. Present the rules of ADAPT grammar.
8. Describe correct specification of miscellaneous functions and factors such as cutter size and program sequences.
9. Demonstrate preparation of a simple ADAPT manuscript.
10. Assign students exercises in program writing using ADAPT.

RESOURCE UNIT

The various aspects of determining and organizing the data required for a numerical control system input have been analyzed in the preceding units. In Units 9 and 10 the steps in preparing a control tape were covered. The N/C manuscript was related to conventional planning methods and was shown to be an extension of those methods necessary to the tremendously expanded capabilities of N/C machine tools and to the increased need for preplanning machine operations. Manuscripts are influenced in both format and content by the characteristics of the part, the machine, and the control system.

The Languages of Tape

The manuscript itself is not the most significant new tool available to the tooling engineer. Manual programming is inadequate to take the maximum advantage of the vast potential of numerical control of machine tools. A more significant contribution to manufacturing technology was the development of means of communicating with computers--means of enlisting computer aid in the preparation of control programs of awesome complexity. The breakthrough at Parsons Engineering Company was followed up in succeeding years by work at MIT and at Armour Research Institute; this work resulted in the genesis of the APT (Automatic Programmed Tool) language. Members of the AIA contributed more than 50 million man-hours to the development of APT and of the mathematical computer routines that it actuates in the development of machine control tape.

APT is not the only new language that has been developed, nor is it the only one in use. Others of current significance include AUTOPROPS, AUTOSPOT, CAMP I, CAMP II, PRONTO, SNAP, AUTOMAP, AUTOPROMPT, SPLIT, SYMPAC, and ADAPT. Some of these languages have been devised to function with special computers, others to perform special functions. Some were invented with the needs of positioning systems foremost, and others especially for contouring.

The use of computer-assisted parts programming has until recently been limited to members of the AIA and to other concerns who devised their own special languages. AIA members used APT first in the field trial version and later in the revised APT II and APT III forms. Early computer programs were developed for use with the larger computers; the present APT III is used in conjunction with the IBM 7094. Because of the massive investment of time and money by the AIA members, the APT languages have been held proprietary, and their use restricted to members only.

Because of this restriction, but also to fill a fast-growing need for a similar language to fit the smaller computers, ADAPT was developed and made available to the trade in 1964. The publication of ADAPT makes computer-assisted programming feasible for practically all activities that need continuous or frequent local tape preparation, but do not have larger computers available to them. And this usually includes training activities.

ADAPT

The ADAPT language is English-like and problem-oriented. It is compatible with APT III, since it uses only words available in the master language, but ADAPT does not comprise as many words nor as many optional procedures. ADAPT may be used on small digital computers; it has full two-dimension geometric capability. By using simple terracing techniques, the system can be "fooled" into producing three-dimensional contours. Commands are available for tool movements and for the preparatory and miscellaneous functions used in simple manuscripts, as described in preceding units.

ADAPT is easy to use, as is seen from the following sample translations:

ŚETPT = PØINT/3, 4	This defines a point with coordinates x = 3, y = 4 that is the setup point for tool(s) used in the operation.
LI = LINE/3, 4, 7, 8	This defines a straight line through the points with coordinates x3, y4 and x7, y8.
ĆUTTER/2, 1250	This describes a cutter 2 inches in diameter with a 1/8 inch radius on the corner.

It must be kept in mind that the computer does not actually understand English, but converts the ADAPT words to digital data. Hence, it is extremely important that all words be spelled exactly as they appear in the ADAPT dictionary. (See American Machinist Special Report No. 554.) For example, the computer would not recognize the word ĆUTER if ĆUTTER were intended. It is just as important to follow the rules of grammar and *punctuation meticulously*, or the computer will fail to interpret correctly.

Adapt Sentence Structure

Both form and order are prescribed for the characters, words, and sentences used in ADAPT. Capital letters are always used. And note the means taken to distinguish troublesome letters and numbers, as follows:

Letter O (oh) is written Ø.
Letter Z (zee) is written Ƶ.
Letter C (cee) is written Ć.
Letter I (eye) is written I.
Letter S (ess) is written Ś.

Numeral 0 (zero) is written 0.
Number 2 (two) is written 2.
Letter G (gee) is written Ģ.
Number 1 (one) is written 1.
Number 5 (five) is written 5.

Words used in ADAPT do not exceed six characters. Punctuation, such as the comma and slash (/), is vital in its placement. It is rumored that the first Mariner spacecraft missed Venus because a comma was omitted from the program. Whether or not this is true, it is possible.

An ADAPT sentence is made up of significant parts that have specific relationships to each other and to the message being conveyed. A typical sentence includes a name, a major section, and a modal section:

- NAME: Defined as any geometric definition which might be referred to later in the program. It can be any combination of not more than six letters and numbers that do not form any standard word in the ADAPT dictionary.
- MAJOR SECTION: Consists of ADAPT words, as spelled in the ADAPT dictionary, defining geometric parameters, motion commands, special instructions, and the like. Some major section words are PØINT, LINE, and FEDRAT. Major section words are always followed by /.
- MODAL SECTION: follows the slash and defines the particular variables of the major section.

An example of an ADAPT sentence is:
Name = Major/ Modal
CIR 1 = CIRCLE / 1.0, 2.5, 0.5

Translated, CIR 1 is a circle; the coordinates of its center are x1.0, y2.5; its radius is 0.5.
Another example:
CUTER 1 = CUTTER / 0.5, 0.125
That is, CUTER 1 is a cutter of diameter 0.5 and corner radius 0.125. In the second example the name resembles the ADAPT word CUTTER but is sufficiently different to be distinguished by the computer, while easily recognized by the programmer, key punch operator, and machine operator. Other cutters listed in the preliminary manuscript can be named CUTER 2, CUTER 3.

Geometric Definitions

Handout Sheets No. 11-1, 11-2, and 11-3 show in detail some of the possibilities in ADAPT for geometric definition of points, lines, and circles. Other geometric figures can be described using APT and ADAPT; the latter is much more restricted as to variety of methods. No attempt is made here to define all the words and techniques possible with ADAPT: only sufficient introduction is given to make possible the use of available ADAPT dictionaries. Handout Sheet No. 11-4 provides a list of major words which can be used for student vocabulary training.

Special Adapt Word Instructions

Among the many ADAPT words that initiate motions, computer functions, reader functions, and the like are the following:

END	This word stops the director and the machine tool. It indicates the end of a program or the necessity for a FRØM command to follow if the program is to continue.
STØP	This word turns off the machine tool, but does not always shut off the spindle, depending upon the type of machine tool or control unit.

SPINDLE/ØFF	These words will stop the spindle and, on some machines, will stop the coolant.
SPINDLE/ØN	These words will start the spindle at its last rpm setting. For a change of spindle speed, the statement would be in the form SPINDLE/1800, CLW which would start the spindle at 1800 rpm clockwise. For counterclockwise motion, CCLW would replace CLW.
CØØLNT/ØN	This statement is not much used; the manner in which the coolant is applied is specified, e.g., CØØLNT/ FLØØD. Mist or other conditions can be specified. The use of ØFF after the slash turns the coolant off.
FEDRAT/	This word followed by a rate in inches per minute will set the desired feedrate on machines equipped to accept this command.
TØLER/	This word permits specifying tolerances (limits of error) in following the planned motions required to produce curves, circles, and the like. Such patterns are produced by a series of straight lines, and the computer must be told the permissible variation from the true curve.

Motion Statements

Specific start-up statements and motion commands have been devised to ensure that the machine tool will start in the correct direction. In these statements the positions of the slash and commas are vital; omission or incorrect placement of either will cause the computer to stop or to deliver a faulty tape. Handout Sheet No. 11-5 illustrates the essential commands. In formulating motion statements, the sentence structure must be restricted to standard forms, and the correct forms of geometric definition must be used in the modal area of the sentence.

A statement such as GØ/TØ, L1 will cause a tool to be moved to a previously defined line, L1. If the line has not been previously defined, the statement can be in the form GØ/TØ/, (L1 = LINE/x, y, x, y). Once the tool is in correct relationship to the part, changes of direction can be specified in the following manner: GØ RGT/L1. This directs a turn to the right with respect to the direction in which the tool is already moving along L1, and L1, if not previously defined, could be defined at this time.

Point-to-point positioning can also be accomplished by a statement in the form GØTØ/ point. This starts the cutter in motion and takes it to the point designated or specified. This statement always puts the cutter center on the point; it is commonly used with the major word SETPT, meaning the setup point. Handout Sheet No. 11-6 illustrates a sample program.

Programming Repetitive Cycles

It is often necessary to repeat a machining cycle, short or lengthy, at different points in the operation. ADAPT provides for repeats, which are essential in positioning operations such as turret drilling. The ADAPT routines are not as efficient as those found in APT, and they require more computer time, but about the same results in terms of control can be accomplished.

In both APT and ADAPT the word assigned to a repeat sequence is MACRØ. Macro is an English prefix meaning large or involving large quantities, the opposite of micro. In ADAPT it designates a macrocommand, i.e., a complete group of statements which are to be repeated. A name is assigned to each macro, and it is stored for future use, not executed at the time it is defined. At the time of use, the group of statements need not be repeated; only the macro name is required.

A few of the special words associated with macrocommands are:

MACRØ/	This word is always written with the slash, which is followed by the identification of the variables which will be applied.
TERMAC	This word is used alone in the statement, without punctuation, to terminate the macro.
CALL	This word is an execution statement which causes a previously defined macro to be performed.

A simple example of the use of a macro is given in Handout Sheet No. 11-7.

Computer Processing Work Flow

Study of the work flow involved in the preparation and use of computer-assisted N/C programs will reveal the tremendous potential for time savings that is inherent in the system. A typical work-flow diagram is presented in Fig. 11-1.

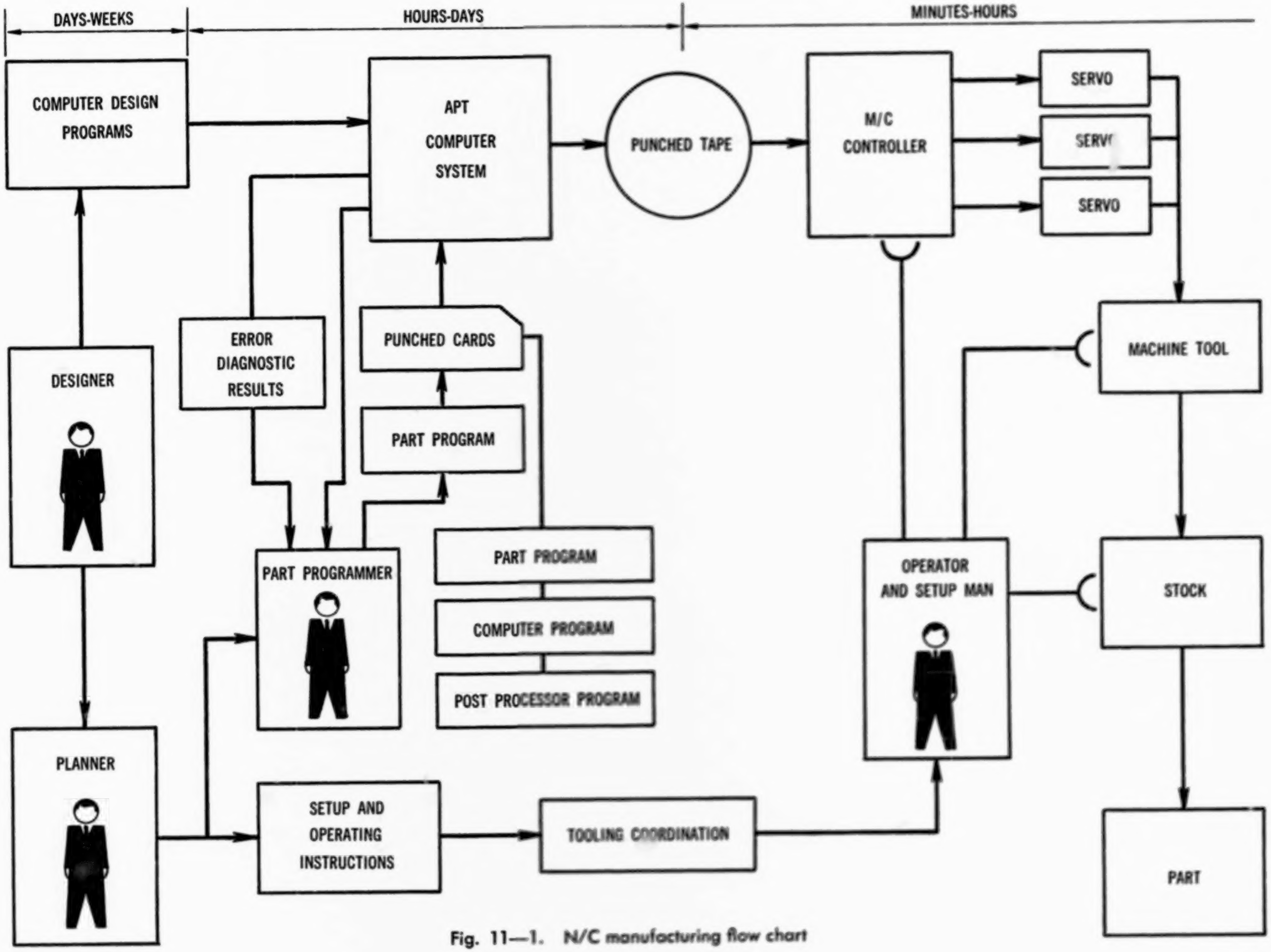

DAYS-WEEKS
HOURS-DAYS
MINUTES-HOURS
COMPUTER DESIGN PROGRAMS
APT COMPUTER SYSTEM
PUNCHED TAPE
M/C CONTROLLER
SERVO
SERVO
SERVO
DESIGNER
ERROR DIAGNOSTIC RESULTS
PUNCHED CARDS
PART PROGRAM
MACHINE TOOL
PART PROGRAMMER
PART PROGRAM
COMPUTER PROGRAM
POST PROCESSOR PROGRAM
OPERATOR AND SETUP MAN
STOCK
PLANNER
SETUP AND OPERATING INSTRUCTIONS
TOOLING COORDINATION
PART

Fig. 11—1. N/C manufacturing flow chart

Manuscripts prepared in longhand English are converted to ADAPT, using a manuscript form similar to that of Handout Sheet No. 11-8, with which keypunch operators are familiar. Following the keypunch operation, the cards are usually verified by comparing a typeout with the original ADAPT manuscript.

The cards form a "deck" which is fed to the computer with the standard ADAPT deck and the post-processor deck. The post-processor deck furnishes specific data relative to the capabilities and limitations of a particular machine. When the post-processor deck is not available, the programmer must insert any necessary modifications, sometimes on a trial-and-error basis.

Upon completion of each stage of the process, a typeout is produced to verify the accuracy of the work to that point. A large part of the programmer's time is spent in error analysis and related reworking operations. Rework, insertion of engineering changes, and other minor changes are often performed in the computer, but many firms provide accessory equipment that permits the programmer to perform necessary calculations and make the new cards required. This reduces the demand for computer time and provides an effective training activity.

INSTRUCTIONAL TECHNIQUES

References

ADAPT for the 1620-1311 Data Processing System. White Plains, N. Y.: IBM Corporation, 1964.
Hori, S., Computer Primer for Non-Computists. Chicago, Numerical Control Society, 1965.
"The Languages of Tape" (Special Report No. 545). American Machinist (Jan. 6, 1964).
"Production Man's Guide to APT-ADAPT" (Special Report No. 554). American Machinist (July 22, 1964).

Handout Materials

ADAPT Method and Vocabulary Sheets (Handout Sheets No. 11-1 through 11-7)
ADAPT Worksheet Blank (Handout Sheet No. 11-8)
Copy of Fig. 11-1
ADAPT Worksheet Problems 1-20 (Handout Sheet No. 11-9)

Audio-Visual Materials

Overhead projector transparencies of handout materials (instructor-made)

Student Activities

1. Work ADAPT Worksheet Problems 1-20.
2. Research the definitions of ADAPT words on Handout Sheet 11-4.

Handout Sheet No. 11-1

ADAPT METHODS OF DESCRIBING A POINT

By coordinates

PØINT / X, Y, Z,

PØINT / X, Y, (*)   Z is assumed to be zero if omitted

Example: PØINT / 2, 3, 2

By the intersection of 2 lines

PØINT / INTØF, (LINE? / X_1, Y_1, X_2, X_2,), (LINE/ X_3, Y_3, X_4, Y_4)

Example: PØINT / INTØF, (LINE / 2, 0, 2, 4), (LINE / 0, 2, 4, 2)

By the intersection of a line and a circle

PØINT / **, INTØF, (LINE / X_1, Y_1, X_2, Y_2,), (CIRCLE / X, Y, radius)

Example: **Modifier: X LARGE, X SMALL, Y LARGE, Y SMALL

Example: PØINT / Y LARGE, INTØF, (LINE 2, -2, 2, 4),
(CIRCLE / 2, 1, 1)

By the intersection of 2 circles

PØINT / **, INTØF, (CIRCLE / X, Y radius), (CIRCLE / X, Y, radius)

** Modifier: Same as above

Example: PØINT / Y LARGE, INTOF, (CIRCLE / 1, 1, 1.328),
(CIRCLE / 2, 2, 2)

By the center of a circle

PØINT / CENTER, (CIRCLE / X, Y, radius)

Example: PØINT / CENTER, (CIRCLE / 2, 2, 1)

By a point on a circle which an extended radius would make a specified angle with the + X axis

PØINT / (CIRCLE / X, Y, radius), ATANGL, the angle in degrees COW

Example: PØINT / (CIRCLE / 0, 0, 2.328), ATANGL 45

Handout Sheet No. 11-2

ADAPT METHODS OF DESCRIBING A LINE

Through 2 Points

LINE / X_1, Y_1, X_2, Y_2

Example: LINE / -2, 2, 4, 2

Through a point and tangent to a circle

LINE / (PØINT / X, Y,), **, TANTØ, (CIRCLE / X, Y, Radius)

Example: LINE / (PØINT / -2, 2), LEFT, TANTØ, (CIRCLE / 3, 2, 1)

** indicates the use of RIGHT or LEFT. These are applied looking from the point towards the circle. LEFT would indicate the line was to the left of the circle.

Tangent to 2 circles

LINE / **, TANTØ, (CIRCLE / X, Y, Radius), **, TANTØ, (CIRCLE / X, Y, Radius)

** indicates RIGHT or LEFT in any combination and are applied looking from the first circle written to the second.

Example: LINE / RIGHT, TANTØ, (CIRCLE / -4, 4, 2), LEFT, TANTØ, (CIRCLE / 4, 1, 1)

Passing through a point and making a specified angle with the X axis

LINE / (PØINT / X, Y), ATANGL, Specify angle with X axis.

Example: LINE / (PØINT / -2, 2), ATANGL, 0

Through a point and parallel to a line

LINE / (PØINT / X, Y), PARLEL, (LINE / X_1, Y_1, X_2, Y_2)

Example: LINE / (PØINT / -2, 2), PARLEL, (LINE / 0, 0, 4, 0)

Through a point and perpendicular to a line

LINE / (PØINT / X, Y), PERPTØ, (LINE / X_1, Y_1, X_2, Y_2)

Example: LINE / (PØINT / 4, 2), PERPTØ, (LINE / 0, 0, 0, 4)

Parallel to a given line and offset a given distance

LINE / PARLEL, (LINE / X_1, Y_1, X_2, Y_2), ***, Distance

*** may be X LARGE, X SMALL, Y LARGE, or Y SMALL. These mean that the line is offset in a positive X direction if it is X LARGE and negative if it is X SMALL.

Example: LINE / PARLEL, (LINE / 0, 0, 4, 0), Y SMALL, 2

Handout Sheet No. 11-3

ADAPT METHOD OF DESCRIBING A CIRCLE

By the coordinates of the center and the radius

```
CIRCLE / X, Y, Radius

Example:  CIRCLE / 2, 2, 2
```

By the center and a line to which it is tangent

```
CIRCLE / CENTER, (PØINT / X, Y), TANTØ, (LINE / X, Y, X, Y)

Example:  CIRCLE / CENTER, (PØINT / 2, 2), TANTØ, (LINE 0, 0, 0, 4)
```

By the center and a point on the circumference

```
CIRCLE / CENTER, (PØINT / X, Y), (POINT / X, Y)

Example:  CIRCLE / CENTER, (PØINT / 2, 2), (PØINT / 0, 2)
```

By three points on the circumference

```
CIRCLE / (PØINT / X, Y), (PØINT X, Y), (PØINT / X, Y)

Example:  CIRCLE / (PØINT / 4, 2), (PØINT / 0, 2), (PØINT / 2, 0)
```

By the center and a circle to which it is tangent

```
CIRCLE / CENTER, (PØINT / X, Y), **, TANTØ, (CIRCLE / X, Y, Radius)
```

** indicates either SMALL or LARGE. To determine which one to use, consider that the circle being defined may be 2 different diameters and be tangent to another circle. Use SMALL if it is the smaller diameter and LARGE if it is the larger.

```
Example:  CIRCLE / CENTER, (PØINT / 2, 2), SMALL, TANTØ,
(CIRCLE / 5, 2, 1)
```

By intersecting tangent lines and the radius

```
CIRCLE / **, (LINE / X, Y, X, Y), **, (LINE / X, Y, X, Y), RADIUS,  $
Radius of the circle
```

** indicates X LARGE, X SMALL, Y LARGE, Y SMALL. These mean that the circle center is in a positive direction if LARGE and a negative direction if SMALL.

```
Example:  CIRCLE / X LARGE, (LINE / 0, 0, 0, 4), Y LARGE,  $
(LINE / 0, 0, 4, 0),  RADIUS, 2
```

NOTE: Use of $ means end of line to be continued on next line.

Handout Sheet No. 11-4

BASIC ADAPT VOCABULARY LIST

For:

Definitions

P0INT
LINE
CIRCLE
INT0F
CENTER
RADIUS
PLANE
RIGHT
LEFT
MATRIX
P0CKET
PARIEL
X LARGE
X SMALL
Y SMALL
Y LARGE
Z LARGE
Z SMALL
TANT0
ATANGL

Motions

FR0M
G0T0
G0DLTA
G0
G0RGT
G0LFT
TLLFT
TLRGT
G0FWD
T0
0N
PAST
INDIRP

Other

PARTN0
REMARK
T00LN0
CUTTER
SPINDL
INT0L
0UTT0L
T0LER
MACHIN
ST0P
FINI
FEDRAT
THICK
COPY
MACR0
INDEX
RESERV
$$

Punctuation

/	Slash
,	Comma
(	Left Parenthesis
)	Right Parenthesis
=	Equal Sign
$	Single Dollar Sign
.	Decimal Point
-	Minus Sign
*	Asterisk

Handout Sheet No. 11-5

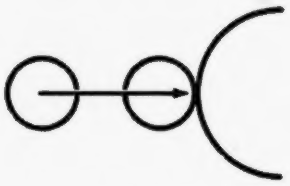
ADAPT METHODS OF STATING MOTION

Common Motion Instructions

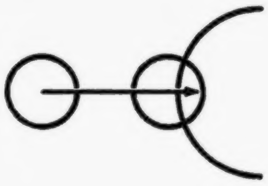
FRØM

GØDLTA / -- Go Delta, indicates an incremental movement

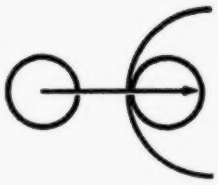
GØ/TØ
GØ/ØN
GO/PAST



GØ / TØ



GØ / ØN



GØ / PAST

GØ / -- Omission of TØ, ØN or PAST means that ADAPT will assume TØ.

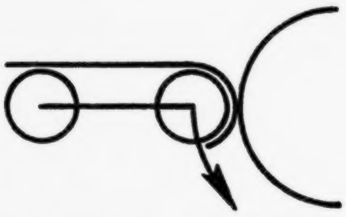
INDIRP / -- In direction of point. Used as a start command.

GØLFT / - Go left
GØRGT / - Go right
GØFWD / - Go forward

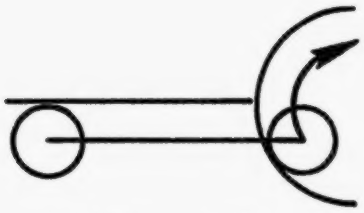
in respect to the last motion, looking forward from the last point

TLRGT, - Tool right
TLLFT, - Tool left

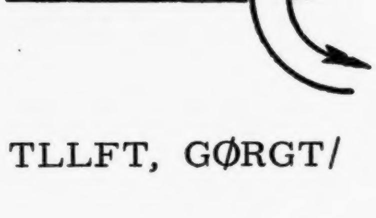
Statement tells ADAPT which side of the line defined the tool should be on



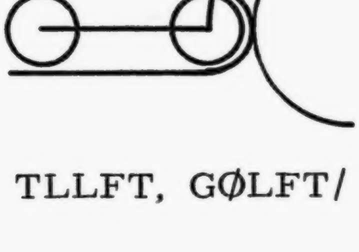
TLRGT, GØRGT/



TLRGT, GØLFT/



TLLFT, GØRGT/

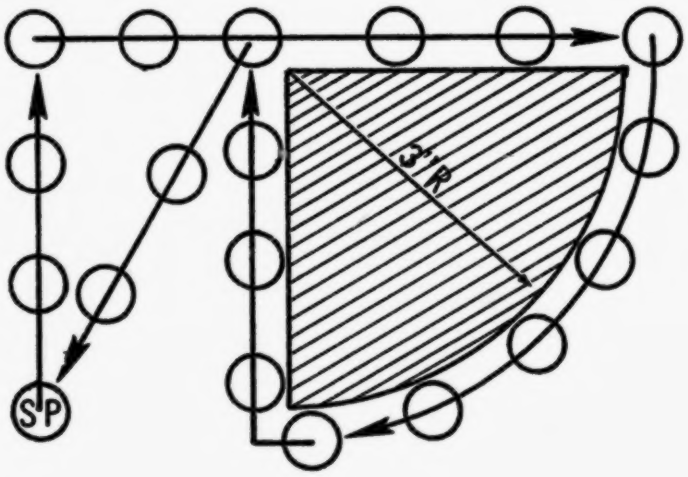


TLLFT, GØLFT/

Handout Sheet No. 11-6

SAMPLE ADAPT PROGRAM

The pie-shaped part to be machined is hatched. Circled lines show cutter path from set point to part and return.



```
PARTNØ / 703

REMARK  SAMPLE PART

MACHIN / TRW, 21

CUTTER / 1.5, .125

INTØL / .001

ØUTØL / .001

SETPT = PØINT / 0,0

  TI = PØINT / 6,6

CI = CIRCLE / 6, 6, 3

FRØM / SETPT

INDIRP / 0, 6

GØPAST / (LI = LINE / 6, 6, 9, 6)

TLLFT, GØRGT / LI

GØRGT / CI

GØRGT / (L2 = LINE / 6, 6, 6, 0)

GØTØ / SETPT

STØP

FINI
```

Handout Sheet No. 11-7

MACRØ

The word MACRØ is short for macro command. In ADAPT, it designates a single statement that refers to a group of part programming statements. A name is assigned to the macro and it is stored for future use. The macro is not executed at the time of definition.

Special words associated with macros:

MACRO is followed by a slash (/) and the identification of the variable or variables which will be applied.

TERMAC is used alone to terminate the macro.

CALL is used to command that the macro be executed in the part program.

Example:

```
*** . . . . . . . . . .  $$ Whatever precedes the macro

NAME=MACRØ / X . .       $$ Macro is called NAME and has a variable called X.

GØTØ / X, 1, 0 . . . .   $$ Go to x=X, y=1, z=0

GØDLTA / 0, 0, -1 . .    $$ Plunge 1 inch.

GØDLTA / 0, 0, +1 . .    $$ Withdraw 1 inch.

TERMAC . . . . . .       $$ This completes the macro definition.

*** . . . . . . . . . .  $$ At this point any additional statements may be inserted.

CALL / NAME, X=1 .       $$ Perform the defined operations with X equal to 1.

CALL / NAME, X=1.5       $$ Ditto with X=1 1/2

CALL / NAME, X=2         $$ Ditto with X=2

CALL / NAME, X=2.5       $$ Ditto with X=2 1/2

CALL / NAME, X=3         $$ Ditto with X=3

. . . . . . . . . . . .  $$ Go on with the rest of the program
```

Handout Sheet No. 11-8

ADAPT WORKSHEET

ADAPT PART PROGRAM SYMBOLIC DATA

DECK NO.____ PROGRAMMER____ DATE____ PAGE____ OF____ JOB NO.____

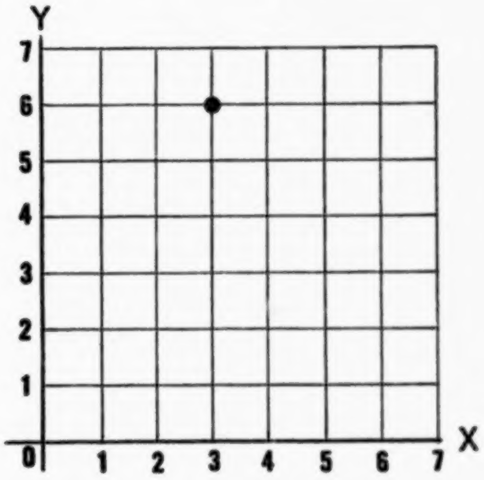
SYMBOL 1 2 6	7 8	72	SEQ. NO. 73 80

Handout Sheet No. 11-9

ADAPT WORKSHEET PROBLEMS (p. 1 of 10)

Work each of the problems that follow, using separate sheets of paper if necessary, and write the answers in the space(s) provided to the right of each problem.

1. What are the coordinates of the point on the diagram below?

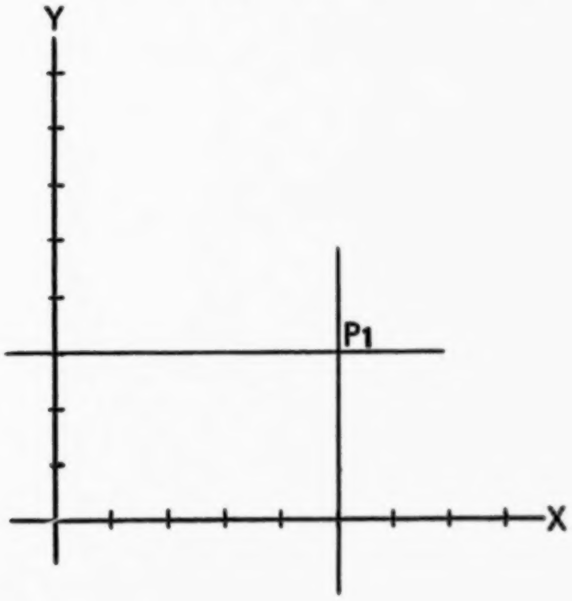


Answer:

x = ______________

y = ______________

2. Write an ADAPT statement that will define point P1.

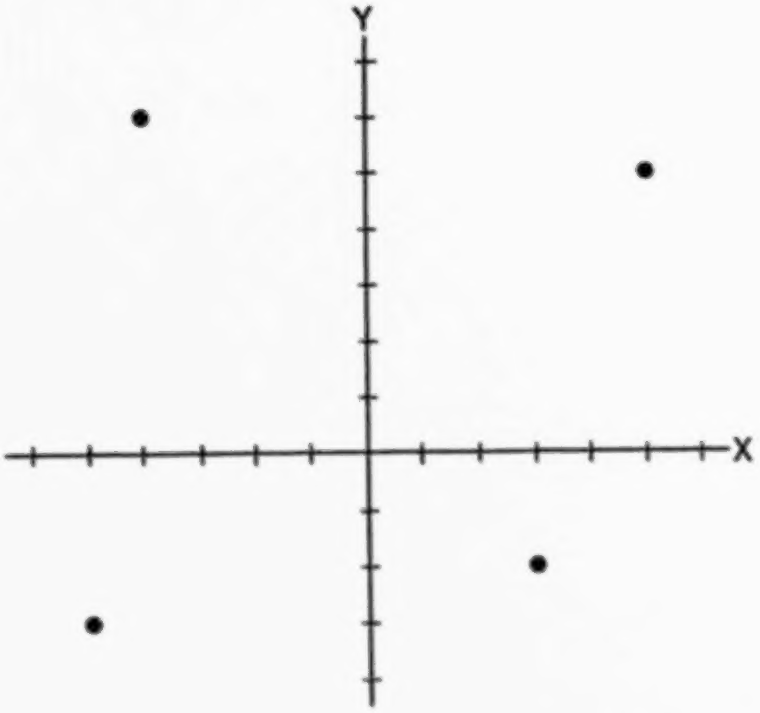


Answer:

________ = PØINT ___, ___, ___

Handout Sheet No. 11-9 (continued)

3. Name and define the four points indicated on the diagram below.



Answers:

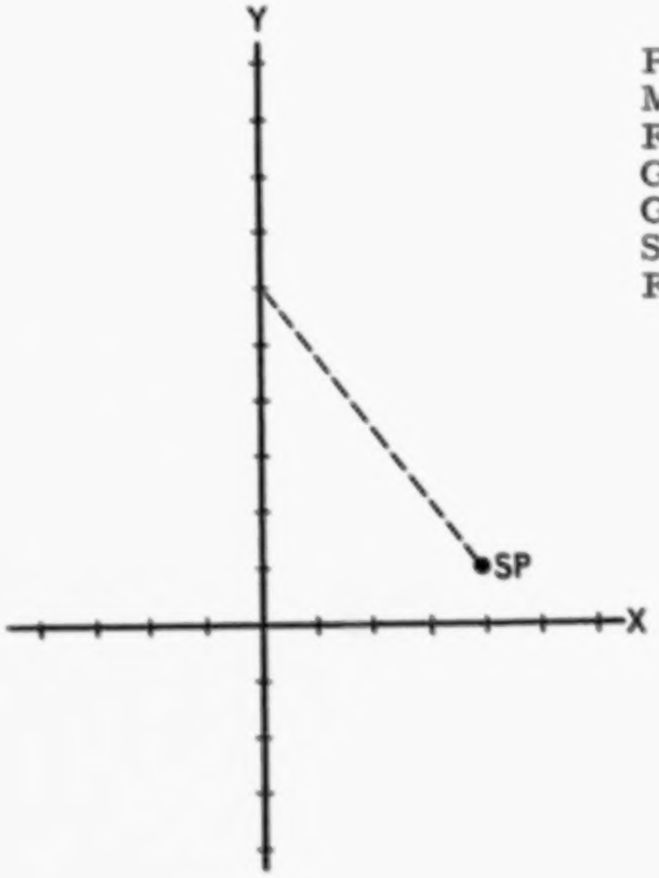
____

____

____

____

4. Complete the following ADAPT program.

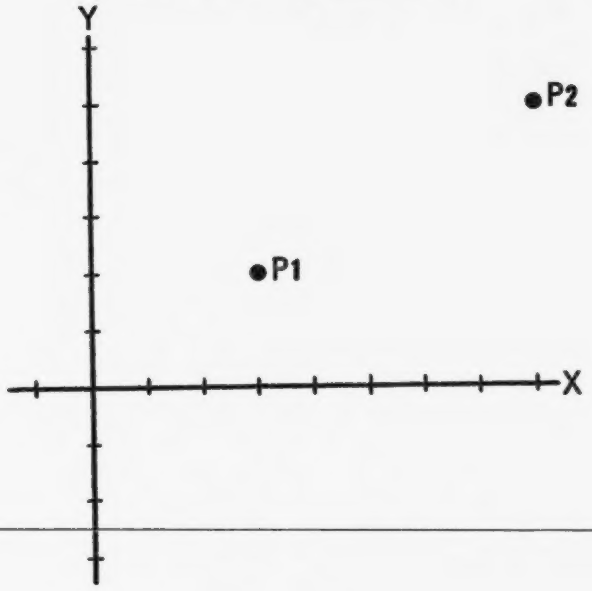


```
PART NØ 47301
MACHIN/CINTI, 2
FROM/ (SP = PØINT/___,___,___
GØ TØ (PØINT/___,___,___
GØ TØ/
STOP, ___
FINI
```

Handout Sheet No. 11-9 (continued)

5. (a) What are the x-coordinate, y-coordinate, and z-coordinate <u>distances</u> from Point Pl to Point P2?

   (b) Write an ADAPT statement that will cause the cutter to move from Point Pl to Point P2.



Answers:

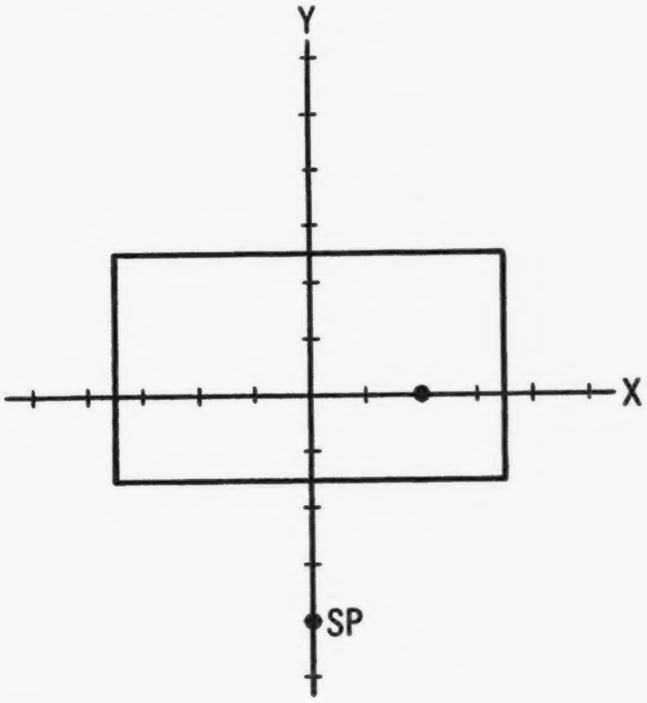
(a) DELTA X = ____________

DELTA Y = ____________

DELTA Z = ____________

(b) GØDLTA/ ___, ___, ___

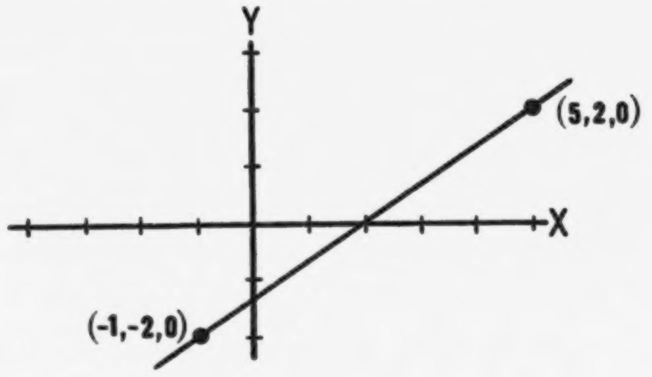
6. Complete the following ADAPT program for drilling a hole at Point (2,0,0). Assume set height is the surface of a part 1.000" thick held down with clamps less than 4.000" thick.



```
PART NØ 47301
MACHIN/ CINTI, 2
FRØM (SETPT = PØINT /___, ___, ___)
GØ TØ/ (SPHIGH = PØINT/___, ___, ___)
GØDLTA/ ___, ___, ___
GØDLTA/ ___, ___, ___
GØDLTA/ ___, ___, ___
GØ TØ/SPHIGH
GØ TØ/SETPT
STØP, ______
FINI
```

Handout Sheet No. 11-9 (continued)

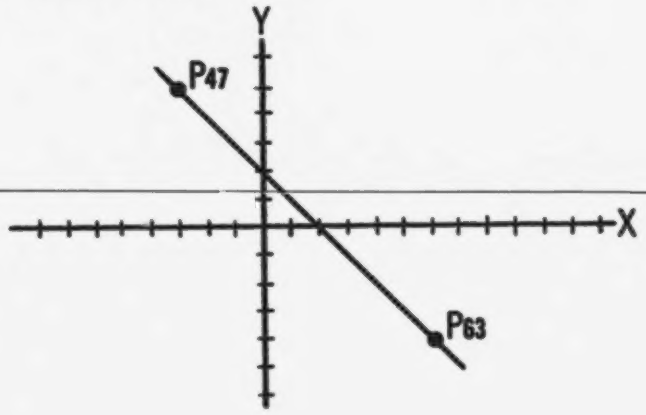
7. Define this diagonal line.



Answer:

Line/ ___, ___, ___, ___, ___, ___

8. Define this line.

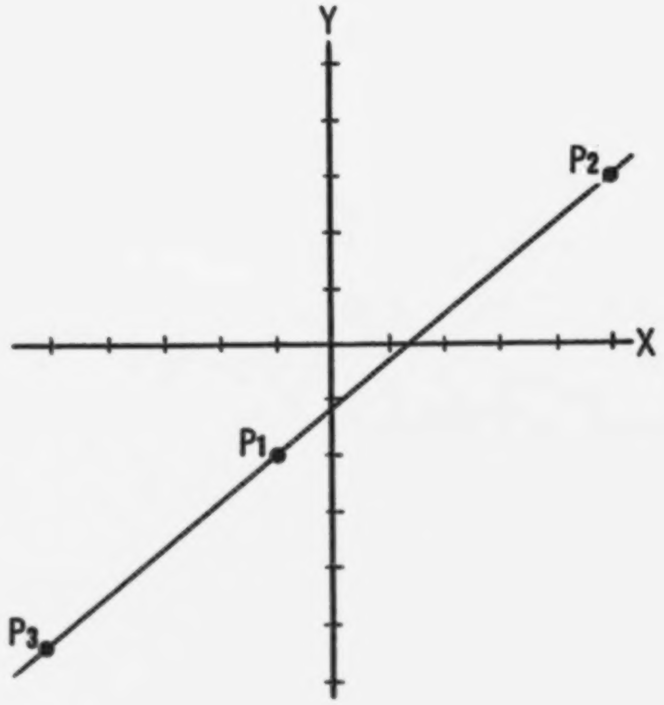


Answer:

Line/ ___, ___

9. (a) Name and define this line.

(b) What are the coordinates of point P3?



Answer:

(a) Name = MAJØR/MØDAL

_____ = _____/_____

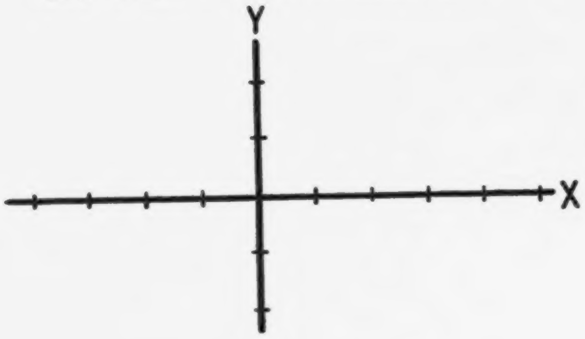
(b) x =

y =

z =

10. (a) Name and define a line parallel to the x-axis.

(b) Name and define a line that coincides (is identical with) the y-axis.



Answer:

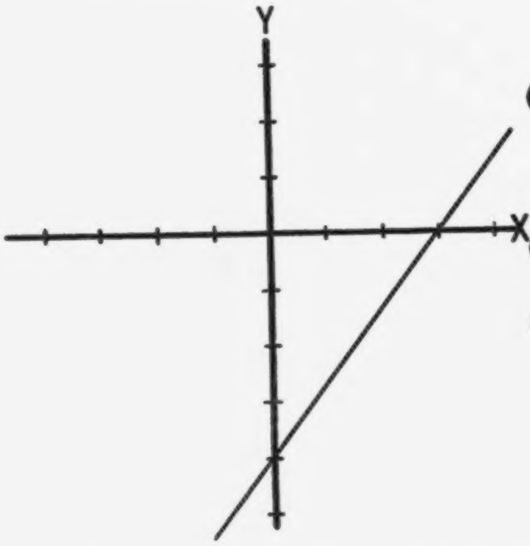
(a) ____________________

(b) ____________________

11. (a) Name and define any two points lying on the line in the diagram below.

(b) Using your symbols for those points, name and define the line.

(c) Using the coordinates for points, name and define the line again.



Answers:

(a) _____ = _____/_____, _____, _____

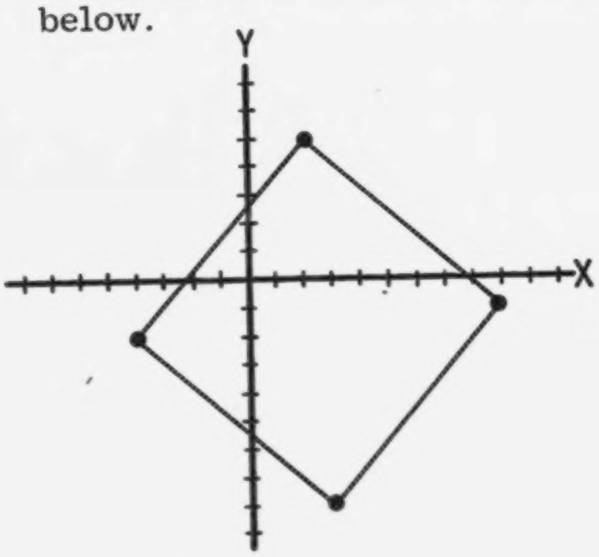
_____ = _____/_____, _____, _____

(b) _____ = _____/_____, _____

(c) _____ = _____/_____, _____, _____,

_____/_____, _____

12. Name and define the four lines that specify the square in the diagram below.



Answers:

____

____

____

____

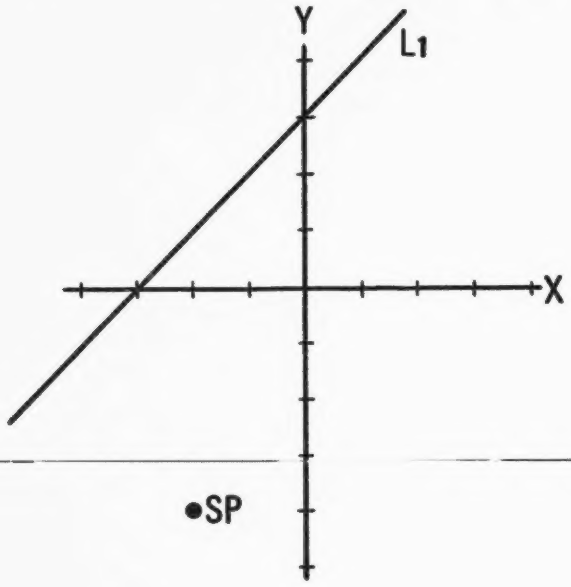
Handout Sheet No. 11-9 (continued)

13. Write the ADAPT statement that will move the cutter.

    (a) From the point SP <u>to</u> line LI ______________________

    (b) From point SP <u>on</u> line LI ______________________

    (c) From point SP <u>past</u> line LI ______________________



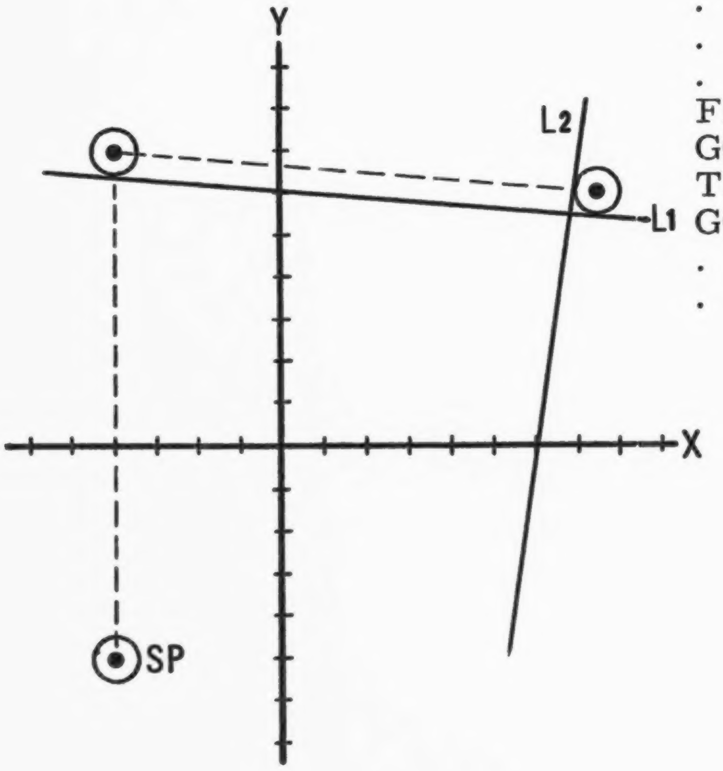
Answers:

(a) ____________________

(b) ____________________

(c) ____________________

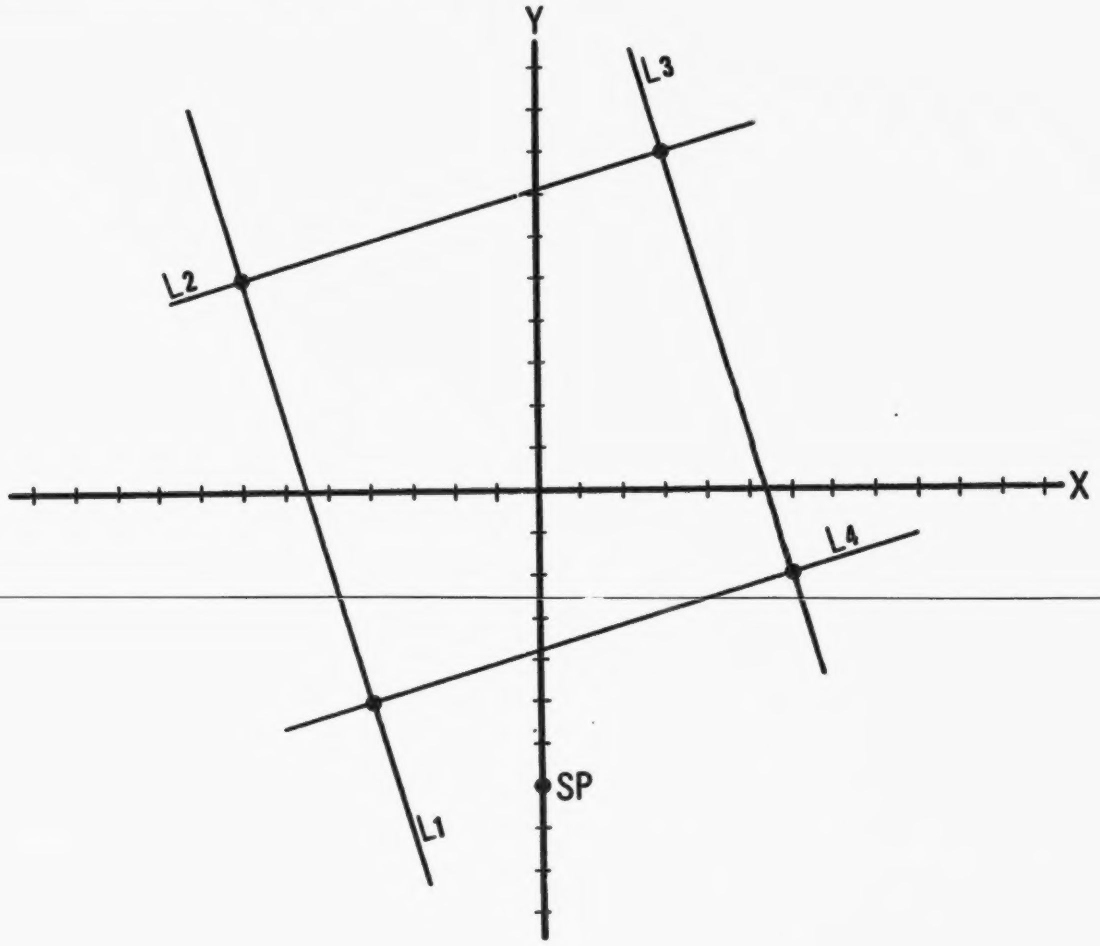
14. Complete this sequence of ADAPT statements to move the cutter as indicated.



```
. . .
. . .
. . .
FRØM/SP
GØ/____, ____
TLLFT, GØRGT /____
GØRGT/____
. . .
. . .
```

Handout Sheet No. 11-9 (continued)

15. Complete the ADAPT program below so that it will cut the square indicated in the diagram.



PARTNØ 55683

MACHIN/CINTI, 2

TOLER/

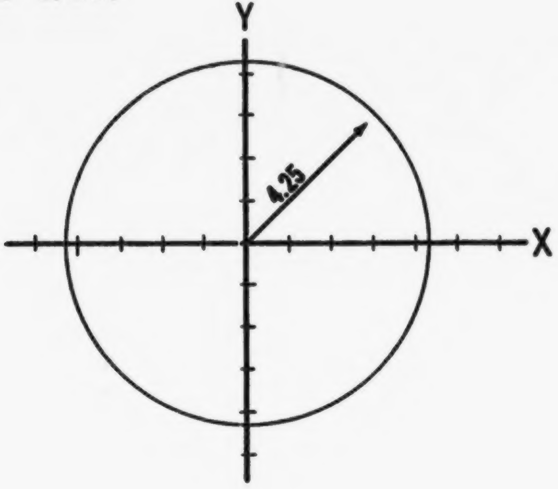
CUTTER/

STØP,

FINI

Handout Sheet No. 11-9 (continued)

16. Name and define a circle whose center is at 0,0,0 and whose radius is 4.25.

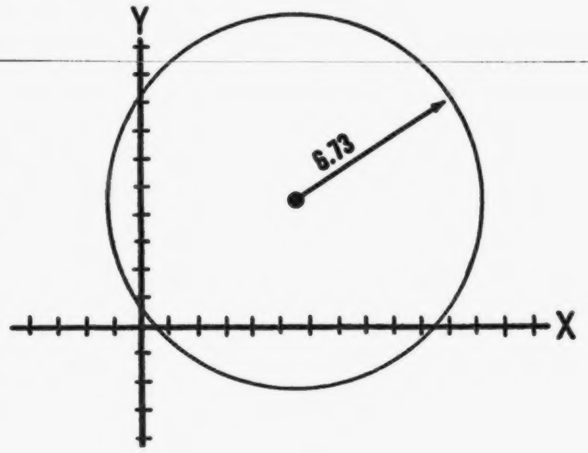


Answer:

______ = CIRCLE / ______, ______

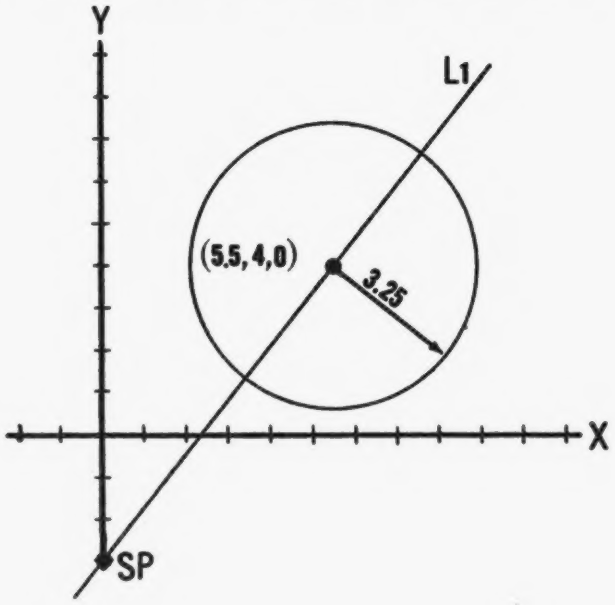
______, ______,

17. Name and define a circle whose center is at point CIRCEN and whose radius is 6.73.



Answer:

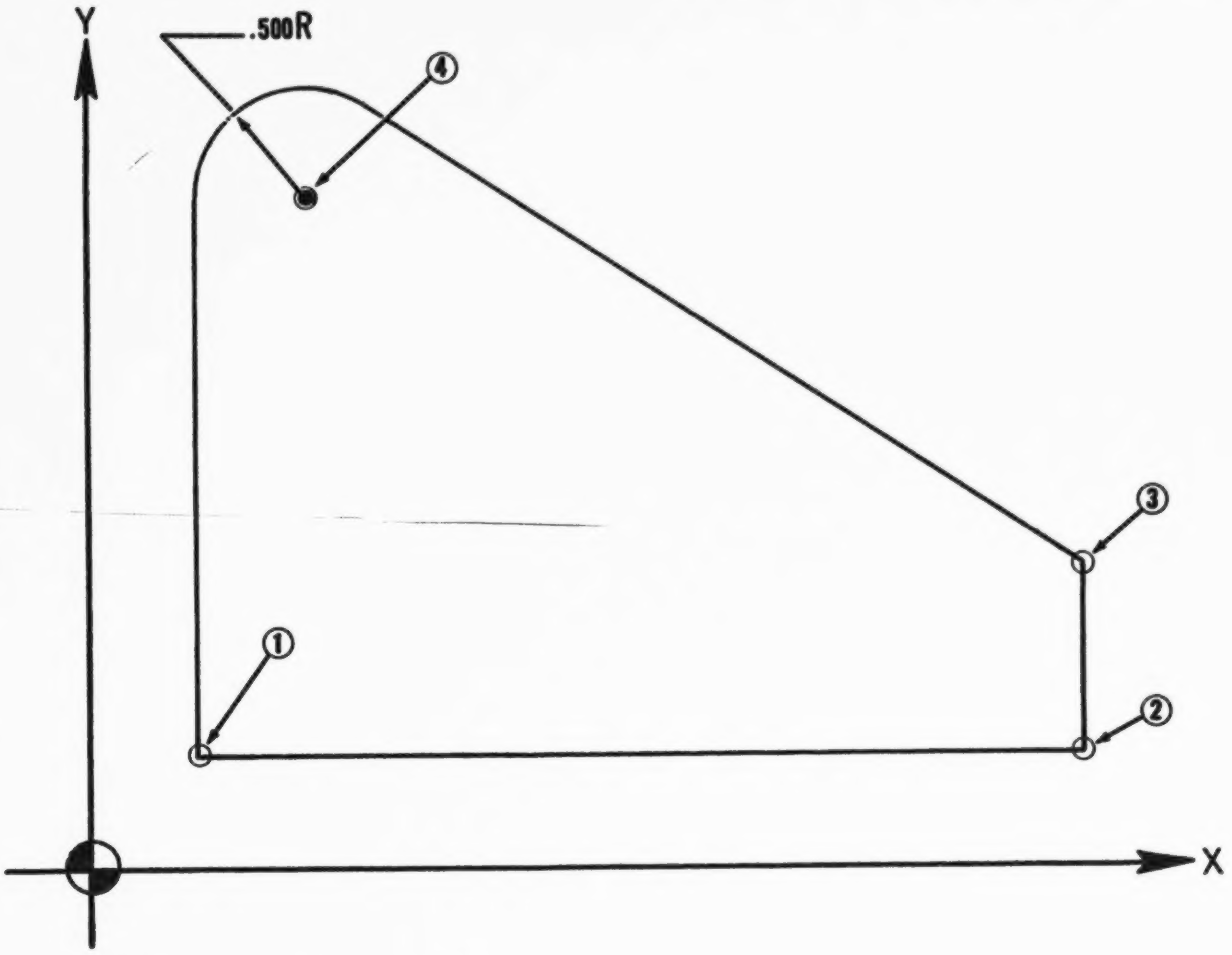
18. Complete the ADAPT program so that the cutter will move from the set point to the circle, then cut around it in a clockwise direction, and then return to the set point.



```
PARTNØ 7685
MACHIN/TRW, 1
_____ = PØINT/0, -3, 0
_____ = PØINT/5.5, 4, 0
L1    = LINE/_____, _____
_____ = CIRCLE/CENTER, _____,
        RADIUS, 3.25
FRØM/_____
INDIRP/5.5, 4, 0
GØ/_____
TLLFT, GØLFT/_____, PAST, _____
GØFWD/_____, PAST, _____
GØTØ/_____
STØP_____
FINI
```

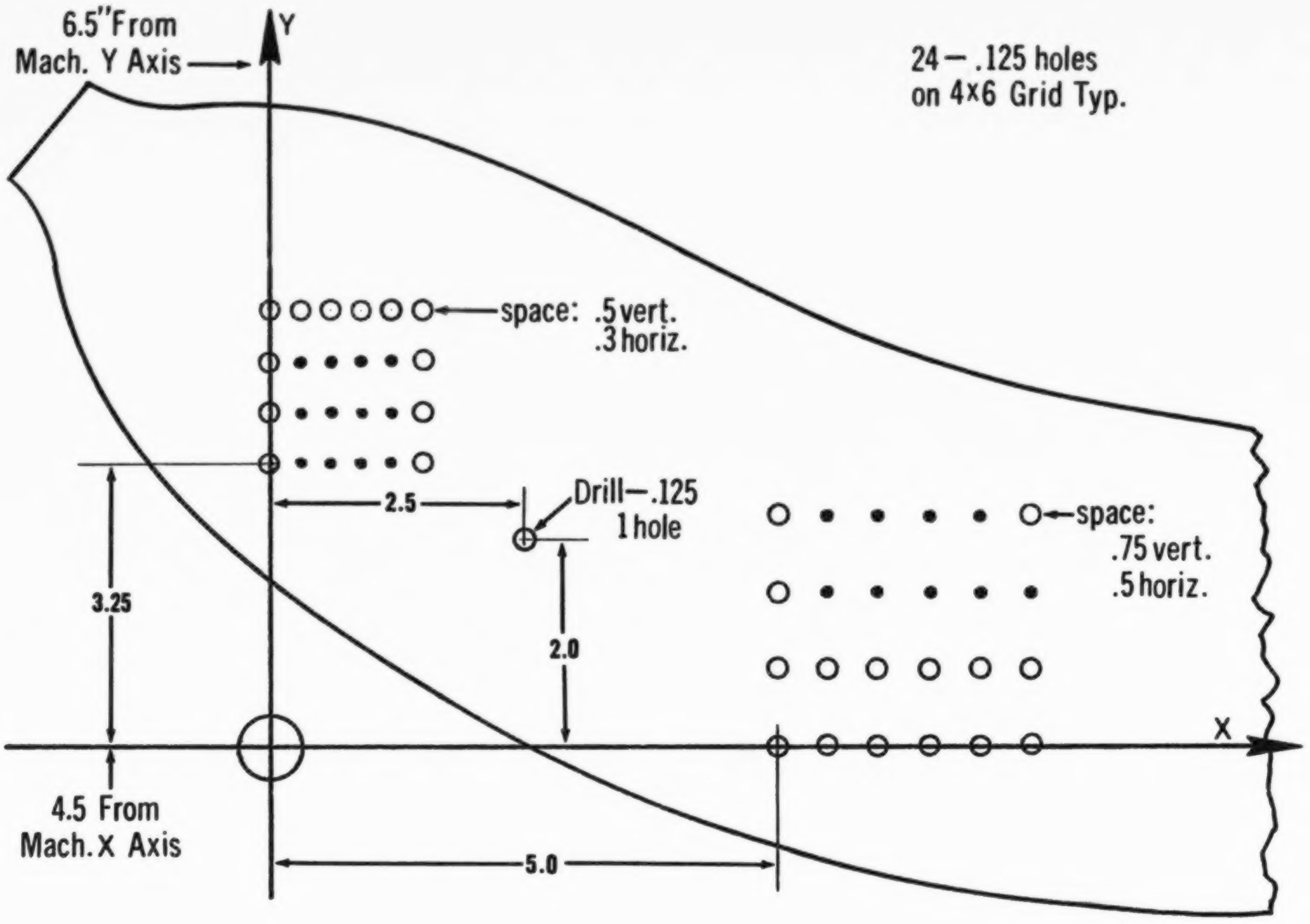
Handout Sheet No. 11-9 (continued)

19. (Questions and directions for this problem to be provided by the instructor.)



Point	X	Y
1	.500	.500
2	4.500	.500
3	4.500	1.037
4	1.000	2.500

20. (Questions and directions for this problem to be provided by the instructor.)


6.5"From
Mach. Y Axis
Y
24 — .125 holes
on 4×6 Grid Typ.
space: .5 vert.
.3 horiz.
2.5
Drill—.125
1 hole
space:
.75 vert.
.5 horiz.
3.25
2.0
X
4.5 From
Mach. X Axis
5.0

unit 12
SUMMARY

PLAN OF INSTRUCTION

Objectives

- To summarize the technological changes occurring as a result of the emergence and growth of N/C as a manufacturing method
- To review the occupational changes inherent in the increasing utilization of N/C in manufacturing
- To define the training needs of the N/C field and relate them to junior college programs

Introduction

1. Review the impact of N/C techniques on the manufacturing processes of industries using machine tools.
2. Discuss the industry rate of adoption of N/C and its effect upon man-hour productivity.

Presentation

1. Evaluate economic implications of N/C.
2. Elaborate on job classification changes resulting from adoption of N/C.
3. Evaluate probable labor-management concerns connected with N/C.
4. Outline skill and knowledge of theory requirements for machinists, machine operators, tool and die makers, programmers, and management groups.
5. Discuss training needs, including retraining.
6. Define guidelines whereby the student may develop a personal training schedule culminating in achievement of all capabilities needed for a career in N/C.
7. Describe the objectives of the two programmers' training courses, Manual Programming and Continuous Path Programming, which normally follow this introductory course.

RESOURCE UNIT

The introduction and development of numerical control of machines has brought many changes, some of them revolutionary, to the field of metalworking manufacturing. Where they originated, these changes have made engineering, as well as the shop operations, more efficient. Product control is at a new high, and preplanning in detail is the tool that put it there. No longer can dimensional omissions be left for the skilled craftsman in the shop to supply as best he can. The variety and number of parts deemed impossible to machine is dwindling rapidly. And product control has provided management with new standards of predictable accuracy, repeatable costs, and schedule adherence.

The new techniques made possible by N/C must be incorporated into part design, and provision must be made to take advantage of them at every stage in the planning/manufacturing process. While a greater flexibility of design is permissible, the discipline of the engineering and tooling functions has been greatly tightened. The experienced machinist or tool and die maker knows many procedures wherein predictable product results can be assured only by specific sequences of operations. New approaches to control must continue to use these tried and proven techniques. Greater precision of control does not mean increased latitude in machining procedures; and the N/C programmer must be familiar with the special techniques that apply to various machine tools and must incorporate them into his programs.

Increases in Productivity

The development of new tooling concepts and the introduction of new tools, which have been accelerating throughout the twentieth century, have resulted in steadily increasing productivity in terms of man-hours worked and dollars invested. The effects of innovation have been cumulative, and today N/C promises savings from 40 to 80 percent over the most efficient conventional methods. A recent study showed that 1950 models were 40 percent more productive than those of 1940 and that productivity of machine tools produced in 1958 was, on the average, 54 percent higher than that of machines available ten years earlier. Numerical control has added new force to the continuing drive to improve the productivity of machine tools.

The applicability of N/C to prototype work and short-run production is one of the most significant factors in its effect on productivity. It is particularly important when the parts to be produced are so complex as to warrant the use of computer programming and tape development. Lead times are so drastically reduced and tooling requirements so minimal that justification of the equipment is no longer a problem. Undoubtedly, Detroit-type automation will continue to be applied where large numbers of like parts are to be produced in a single run. And electronic and hydraulic tracing techniques will still be used wherever the reduced cost of spindles is not offset by longer setup time. But where a large number of different parts are the requirement, the higher cost of N/C equipment will be more than compensated for by the reduction in setup and tooling time. Moreover, tool-use time is higher in N/C machines; and down time for tooling changeover, measurement, and other operator functions is much less than in conventional machines.

When the higher cost of N/C equipment is equated to its increased accuracy, flexibility, productivity, and efficiency, it is inevitable that all industry will be seeking to take advantage of the potentials of N/C.

Changes in Occupational Patterns

When the capabilities and potential of N/C were first examined, it appeared that the great reduction in labor time at the machine tool so equipped would be of serious consequence to the skilled labor force. The reduction in time at the machine for skilled journeymen is a fact--but it is being balanced by the extension of machining techniques to many classes of work once thought totally unsuitable for this method of processing and by the ever-expanding population of product consumers.

The skilled machinist or tool and die maker is far from being rendered obsolete by N/C. Changes in job classification, some not yet defined, are opening new avenues to him. In general, three kinds of changes are taking place: (1) old classifications are having their content altered; (2) some operations are increasing in relative importance compared to others; and (3) new jobs are being established. Much greater importance is being attached to planning; N/C programming is a new job. Both of these depend upon thorough knowledge and understanding of machining setups, operations, and techniques. Unfortunately, there is a diminishing base in industry where skill and experience in these phases can be obtained. And although books will help, the machinist trade cannot be learned without practical application and practice of its skills.

There is every reason to believe that the operator of any N/C machine will be more capable and effective if he has a broad background of experience in conventional machine tool operation. This was confirmed by a survey made among their associates by the members of the workshop team that prepared this guide. (See Appendix.) Similar findings with respect to training needs of N/C personnel were reported as result of a survey on the subject of N/C parts programmers by Northern Illinois University, and a study carried out by Case and Company of Los Angeles indicated a growing differential of higher pay for the higher skill required in N/C operations.

One all-new occupation has developed so far--that of parts programmer. He determines the detailed manufacturing steps and instructions encoded into the control tape. He is responsible for all the decisions on speed, feed, depth of cut, and work positioning, which were formerly in the province of the machine tool operator. He must master much of the basic knowledge required by the machinist or the tool and die maker, and he needs the ability to interpret engineering data, sketches, blueprints, and other specifications just as the conventional planner, methods engineer, and process engineer do.

Competence in additional areas required for N/C work must be identified and developed by N/C personnel. These areas include the capabilities of N/C; the problems and procedures of programming; and new forms of specification, languages, and communication. Although efforts have been made to assign untrained or unskilled persons to N/C equipment, most companies prefer to use men with some skill background, and an increasing number are assigning their most skilled craftsmen.

The members of the tooling team form another category affected by the rise of N/C. The production of required tools has been the chief factor in the lead time between an order and the first finished part, but N/C requires fewer and simpler jigs and fixtures, with major emphasis on fixtures. In one grievance case arbitrated in the automobile industry, toolmakers were given the prerogative of performing programming related to the tooling function on the ground that programming has been a part of the work of the toolmaker in conventional machining operations. Just as tool and die makers must learn the potentials and applications of N/C, so must the engineer, tool designer, and draftsman learn the changes in drawings and in dimensioning systems that contribute to the overall efficiency of the N/C concept.

In all phases of metal working, and in many other industrial processes where machine control is practiced, automation has brought greater productivity and improved quality. To remain competitive, the manufacturer must keep abreast of developments. With N/C, standard machine shop estimation techniques can be used knowing that time studies once recorded are repeatable and that cost estimates can be closely adhered to. For the first time, then, accurate cost and production estimates can be made in support of bids or proposals.

N/C Training Needs

To benefit by the increased capacities of N/C, well-trained personnel are essential. A manufacturer without N/C equipment who has a competitor using it is at a disadvantage; a greater disadvantage is felt by the manufacturer who has invested in N/C machinery but lacks the personnel trained to use it to full advantage. Numerical control is here to stay; training must be given and be absorbed. The most pressing need is to retrain personnel in plants which have begun converting to N/C. And next in order should come the addition to conventional machine technology programs of training blocks that include the theory and practical application of N/C equipment. Drafting, pre-engineering, and engineering students should have access to N/C equipment and techniques so their training will be abreast of technological developments.

By 1967 more than 31,000 persons with N/C capabilities will be needed, it is estimated. And by 1980 almost as many programmers will be required as there are machinists now on the job--some 200,000. These estimates do not include the numbers that will be required for engineering, administration, and management; these must also have background training in N/C.

The training needs that have been identified for each of the different jobs related to N/C vary widely. Much more extensive training is required for programming and maintenance than for other classifications. Formal classroom training cannot be considered the entire training program, though it will greatly improve the program's effectiveness. Equipment must eventually be available at all levels of training. The equipment needed will include:

- Tape preparation equipment, both alpha-numeric and card-tape types
- A positioning system machine tool
- A contouring system machine tool
- Numerically controlled drafting equipment

The availability, in addition, of a computer similar to the IBM 1620 or the Univac 890 will make it possible for classroom instruction to cover all major aspects of N/C.

An N/C Parts Programming Major

A two-year program in N/C parts programming, suitable for inclusion in junior college curriculum patterns, could contribute materially to the fulfillment of the rapidly developing training needs. Such a program should be based upon prerequisites of machine shop training and experience. Four years of on-the-job industrial experience, or two years of vocational high school experience on conventional machines, or an equivalent would not be unrealistic requirements. The following categories should be included in the total curriculum of a typical course.

Conventional Machine Tool Training. Training should be given on conventional machines involving complete machine tool capability, with particular emphasis on machinability, speeds and feeds, tooling, precision machining, contouring, and automatic cycling.

Numerical Control Topics. The material specifically on N/C should include the fundamentals covered in this guide. The laboratory section, in advanced phases, should provide experience in setup and operation of hydraulic tracing equipment and numerical positioning control equipment followed by numerical contouring control in conjunction with the use of an appropriate small computer. Classes in manual parts programming and computer programming should be included as well.

Data Processing. Students should have an option of taking a full complement of courses, including computer operation and FORTRAN language, and of profiting by supplementary courses in engineering data processing.

Mathematics. The student should have a thorough grounding in algebra, trigonometry, and analytic geometry, on a basis of application rather than pure theory. Emphasis should be on the determination of dimensional coordinates and the definition of cutter path and motion variables.

Drafting. Each student should develop advanced capability in blueprint analysis and usable skill in basic line and dimensioning techniques as they are used in orthographic projection, descriptive geometry, lofting, and tool design.

Metallurgy. The student should develop familiarity with the physical properties of materials that affect machinability and processing of parts.

It should be understood that all these courses would have such prerequisites as may be necessary to ensure continuous progress. Existing programs in these fields could be reviewed and revised to establish balanced emphasis on the applied and theoretical aspects.

INSTRUCTIONAL TECHNIQUES

References

Childs, J. J. "Numerical Control and Personnel Requirements," Machine and Tool Blue Book (December, 1961).
Hale, Frank. "The Place of N/C in Vocational Education." Paper presented at the American Vocational Education Seminar, Milwaukee, Wis., December 5, 1962.
"Job Switch for Tool and Die Makers," American Machinist (November 13, 1961).
Minnier, C. G. Estimating for Machine Procurement. Bulletin No. A71-7. Pratt and Whitney Co., 1963.
Numerical Control Part Programmer Survey, 1964. DeKalb, Ill.: S. F. Parson Library, Northern Illinois University.
"Train Students Early for N/C," Iron Age (January 24, 1963).
Wage Rate Survey, 1964. Los Angeles: Case and Co., Inc.
Selected reprints from national trade magazines.

Handout Materials

Career checklist, with courses available at student's school (instructor prepared)

Audio-Visual Materials

New Sounds of Tape. 16 mm. sound color film, 30 min. Produced by Giddings and Lewis. Available on loan from Dayton and Bakewell, 1950 Lovelace Ave., Los Angeles, Calif. 90015
Numeri-turn Lathe. Film produced by Lodge and Shipley. Germaine-Moore Machinery Co., Los Angeles

Student Activities

1. Review the resumés prepared by each student during the first week of classes.
2. List courses needed to fill in training gaps, correlating with courses available at the student's college.
3. Plan a training program leading to attainment of a career goal suggested by the experience and training background and the opportunities suggested by this course.

Appendix A

A SURVEY OF TRAINING NEEDS IN THE AREA OF NUMERICAL CONTROL

Purpose of the Survey

The authors of this survey undertook tne task of determining the opinions of persons engaged in daily work involving numerical control of machine tools. It was planned that the opinions of users of numerically controlled equipment might be used as a background against which to reflect the conclusions of the participants in the 1964 summer workshop. It was proposed to utilize this information both during the preparation of the instructor's guides, which was the purpose for which the workshop activities were planned, and in the evaluation of the materials developed.

It was intended that the training programs developed would have as much practical value in the training of new employees as in the more immediate task of retraining those journeymen machinists who will endeavor to make the transfer and transition from more conventional machine tools and control techniques to numerical control.

Method of Survey

A questionnaire was developed and circulated to 45 employees of industrial concerns participating in the workshop program. Random distribution to a variety of employee classifications was accomplished through the personnel or training departments of the concerns permitting this sampling. The following users of numerically controlled equipment participated: Rocketdyne, Autonetics, General Dynamics, Burgmaster Corp., U.S. Motors, Nor-Air, and Lockheed California Company.

Nature of the Group Surveyed

Twenty-eight employees responded. Of these, ten were in supervision; six in parts programming; five were machine operators or machinists; two engineers; two tool designers; and one each was employed in drafting, service or maintenance, and sales.

An average of 17 years of industrial experience was reported, of which an average of four years had been spent directly involved with numerical control. This figure takes on added significance when it is considered in light of the fact that numerical control, as a significant manufacturing technique, dates back to only early 1957.

The questionnaire revealed that the educational background of the responders was quite varied and included the following:

High school	7	Junior college	12
Apprenticeship	5	Baccalaureate	3
Technical school	10	Masters	1
Other levels	4		

Responses to the Questions

1. Question. In your opinion, why is numerical control important?

Answers.

-Contributions to cost reduction in most phases of production and processing	(15)
-Reduction in tooling and setup time	(9)
-Increased sophistication (ability to do the impossible)	(6)
-Progress	(4)
-Machine time savings	(6)
-Reduction of lead time; adaptability to short runs	(4)
-Increased accuracy	(9)
-Scrap reduction; elimination of operator vagaries	(5)
-Increased production rates	(5)

2. Question. Considering all personnel involved in the untilization of numerical control, will more or less training be required for optimum productive application of the technique?

Answers.

-More	(25)
-Less	(2)
-No opinion	(1)

3. Question. Is there a sufficient supply of trained personnel presently available for the field of numerical control of machine tools?

Answers.

-Sufficient supply	(3)	(2 programmers, 1 operator)
-More needed	(24)	

4. Question. Can all of the training be done on the job?

Answers.

-Yes	(5)	(2 programmers, 2 operators, 1 supervisor)
-No	(22)	
-No opinion	(1)	

5. Question. Should training be done as an extension of or in some sense a part of the apprenticeship program?

Answers.

-Yes	(23)
-No	(2)
-No opinion	(3)

6. Question. Who should be responsible for the training of numerical control personnel?

Answers.

-School	(4)
-Industry	(16)
-Trained personnel	(4)
-Manufacturers of tools	(3)
-Joint responsibility of two or more of the above	(2)
-No opinion	(4)

(Several persons specified two or more possibilities.)

7. Question. What classifications do you feel need to be included in a numerical control training program?

Answers.

-Machine operators	(10)
-Programmers	(9)
-Planners	(7)
-Tooling personnel	(7)
-Maintenance personnel	(5)
-Engineers and draftsmen	(4)
-Machinists	(4)
-Designers	(4)
-Supervisors and related	(6)
-All employees	(2)

8. Question. What kinds of things should be included in the selection of personnel for training for numerical control?

Answers. The most significant responses included:

-Machine shop knowledge	(14)
-Mathematics background	(7)
-General education background	(4)
-Tooling background	(4)
-Alertness, willingness to learn, interest	(8)
-Previous training	(5)
-Mental ability	(2)
-Drafting training	(3)
-Job demands (need to know)	(4)

9. Question. What training have you had in connection with the position you now hold or have held in connection with numerical control?

Answers.

-On the job (by the company)	(14)
-None	(4)
-Machine experience	(3)
-Machine tool or control builders	(3)
-Self-taught	(2)
-Blood, sweat, and tears	(1)
-Classroom	(1)

10. Question. What additional training would you like to receive at this time to increase your understanding of numerical control?

Answers.

-Computer programming techniques	(8)
-Basic programming	(5)
-Machine operation	(4)
-Math	(4)
-Machine operation (control system and electronic)	(2)
-Data processing	(2)
-Tool design	(1)
-None	(1)

11. Question. In your opinion, what overall effect will numerical control have on future training needs in the machine utilization fields of industry?

Answers.

-N/C will have to be included in machinist training as a basic feature	(4)
-Will increase the amount and quality of training needed	(3)
-Increase the amount of knowledge of N/C utilization	(2)
-Reduce the numbers of machinists needed	(1)
-Require more technician-level personnel	(1)
-Other general answers	(6)
-No answer	(8)

12. Question. The responders were asked to indicate the order of importance and significance of the areas of training listed below. The ranking, as averaged, was as follows.

Answers.

-Machine tool programming
-Machine tool manipulation
-Machine tool theory
-Trigonometry
-Drafting
-Tool design
-Computer programming
-Analytical geometry
-Calculus
-Data Processing

Summary

The correlation of the opinions expressed here with the casual comments of the participants in the workship sessions was surprisingly high. It can be assumed that those engaged in the N/C field in the plants surveyed prefer a machine tool oriented training program in which a significant part of the training is accomplished outside the plant, possibly in school.

Machine tool manipulation and theory must be retained, supplemented by mathematics, drafting, and tool design in a somewhat conventional vein. New course offerings in programming, both manual and computer-oriented, should be developed, probably practically oriented and with access to numerically controlled equipment, basic computers, and other periphery control and programming equipment.

August 17, 1964

Paul Henry
Robert Illinik

Appendix B

SAMPLE TEST

Part I TRUE - FALSE

Decide whether each of the following statements is true or false. If it is true, black out the space in column 1 of the Standard Form Answer Sheet appended, opposite the corresponding number; if false, black out the space in column 2.

1. Automation and numerical control mean the same thing.
2. New control methods involve less related technical knowledge and more skill on the part of the technician.
3. Machine tool operation involves the function called sensing.
4. The use of a computer makes possible the performance of more complex operations because of accuracy rather than speed of operation.
5. A servo system compares the value of two controlled quantities.
6. Open control systems may be classified as continuous systems.
7. Radio sets are examples of open-control systems.
8. A rheostat is not an example of an open-control system.
9. Positioning systems are basically open-loop systems.
10. The comparator is an error-measuring device.
11. The tape code illustrated at the right is correct and would be correctly read if punched into a control tape.

```
123 45678
0●● ●●●00
0●● ●●●00
●00 00000
0●● 0●000
●●● 00000
0●0 00000
000 00●00
000 00●00
000 0●00●
0●● ●●●00
0●● ●●●00
0●● ●●●00
0●● ●●●00
```

12. The greatest early problem is positioning system design was concerned with oscillations.
13. Amplifying systems may be either electronic, electrical, mechanical, pneumatic, or hydraulic.
14. Tachometers can be considered sensor devices.
15. In digital counting, individual quantities are totaled.
16. Digital computers utilize analog mathematics.

17. The automobile speedometer is an example of a digital device.

18. Binary arithmetic involves the use of the radix of 2.

19. Double-dabbling is a means of converting decimal numbers to binary numbers.

20. Operational speeds and feeds cannot be predicted with any close degree of accuracy.

Part II MULTIPLE - CHOICE

Select the best answer from those given, and then indicate your choice by blacking in the column of the Standard Answer Sheet which corresponds with the number of your choice.

21. When the correct manufacturing procedure for a given part is planned, time, finish, method, and size are:
    1. inseparable in consideration
    2. somewhat dependent upon each other
    3. only remotely related
    4. independent of one another
    5. not the concern of the part programmer

22. The rate of feed for any given machine setup is governed primarily by the:
    1. type of material being cut
    2. type of coolant available
    3. shape of cutting tool utilized
    4. kind of machine tool to be used
    5. none of the above

23. An example of a closed control system would be an electric:
    1. light
    2. sewing machine
    3. fan
    4. toaster
    5. refrigerator

24. Positioning systems use which one of the following as an actuator?
    1. rheostat
    2. servo-valve
    3. stepping motor
    4. relay
    5. none of the above

25. Most standard control systems include a monitor which has read-out capacity. Monitors may be:
    1. manual
    2. recording
    3. automatic
    4. magnetic
    5. none of these

26. The decisions of the operator of a machine are based upon:
    1. training
    2. experience
    3. data available
    4. a control system
    5. the type of machine

27. The key variable that distinguishes automatic equipment from automated units is:
    1. feedback
    2. electronic control
    3. the type of machine
    4. all of these
    5. none of these

28. A computer is necessary in combination with automatic control systems in order to:
    1. make them self-correcting
    2. give program directions
    3. minimize system sophistication
    4. compute rate of change
    5. complete the loop

29. A voltmeter is generally considered to be which type of device?
    1. electronic
    2. mechanical
    3. digital
    4. analog
    5. computational

30. The majority of computers used in machine tool programming are:
    1. parallel type
    2. synchronous type
    3. series type
    4. special purpose type
    5. none of these

Part III MATHEMATICS

Select the best answer from those given, based upon your own calculation. Perform all work on the back of the Standard Answer Sheet. Indicate your choice by blacking in the column corresponding with the number of your choice, in the space provided on the answer sheet.

31. The binary number 10111 is equivalent in the decimal system to:
    1. 116
    2. 72
    3. 35
    4. 23
    5. 15

32. The binary equivalent of the decimal number 16 is:
    1. 101
    2. 111
    3. 1000
    4. 1100
    5. 10000

33. The binary equivalent of the number 36 is:
    1. 1000
    2. 11000
    3. 10100
    4. 100100
    5. 100110

34. The number 0.10011 is the equivalent of which of the following decimal numbers?
1. 19.
2. 1.9
3. 0.19
4. 0.019
5. none of these

35. A 1" hole is to be drilled using a surface speed of 75 fpm. Calculate the correct rpm setting, and select the best from those indicated below.
1. 110
2. 135
3. 200
4. 280
5. 350

36. A milling cutter 2" in diameter is being run in cast aluminum with fpm of 200. Calculate and select below the best rpm setting.
1. 300
2. 400
3. 500
4. 600
5. 700

37. What should be the cutting time in minutes for boring a 5/8" hole to a depth of 3" if 60 fpm is to be used, with a CL of 0.005"?
1. 0.5
2. 1.5
3. 2.5
4. 3.5
5. 4.5

38. When a six-flute end mill is used at 2,500 fpm, what should the feed rate be in inches per minute if the chip load is 0.010" per tooth?
1. 10
2. 13
3. 19
4. 24
5. none of these

39. What is the feed rate in thousandths per revolution in the preceding problem?
1. 0.020
2. 0.040
3. 0.060
4. 0.080
5. 0.100

40. In order to bore a 1.500" diameter hole in a part, with an rpm setting of 1,100 and a chip load of 0.009", what ipm setting should be used?
1. 1.3
2. 5.6
3. 9.9
4. 11.2
5. none of these

STANDARD FORM ANSWER SHEET

	1	2	3	4	5		1	2	3	4	5
1.	0	0	0	0	0	26.	0	0	0	0	0
2.	0	0	0	0	0	27.	0	0	0	0	0
3.	0	0	0	0	0	28.	0	0	0	0	0
4.	0	0	0	0	0	29.	0	0	0	0	0
5.	0	0	0	0	0	30.	0	0	0	0	0
6.	0	0	0	0	0	31.	0	0	0	0	0
7.	0	0	0	0	0	32.	0	0	0	0	0
8.	0	0	0	0	0	33.	0	0	0	0	0
9.	0	0	0	0	0	34.	0	0	0	0	0
10.	0	0	0	0	0	35.	0	0	0	0	0
11.	0	0	0	0	0	36.	0	0	0	0	0
12.	0	0	0	0	0	37.	0	0	0	0	0
13.	0	0	0	0	0	38.	0	0	0	0	0
14.	0	0	0	0	0	39.	0	0	0	0	0
15.	0	0	0	0	0	40.	0	0	0	0	0
16.	0	0	0	0	0	41.	0	0	0	0	0
17.	0	0	0	0	0	42.	0	0	0	0	0
18.	0	0	0	0	0	43.	0	0	0	0	0
19.	0	0	0	0	0	44.	0	0	0	0	0
20.	0	0	0	0	0	45.	0	0	0	0	0
21.	0	0	0	0	0	46.	0	0	0	0	0
22.	0	0	0	0	0	47.	0	0	0	0	0
23.	0	0	0	0	0	48.	0	0	0	0	0
24.	0	0	0	0	0	49.	0	0	0	0	0
25.	0	0	0	0	0	50.	0	0	0	0	0

______________________ Student's Name

__________ Test No.

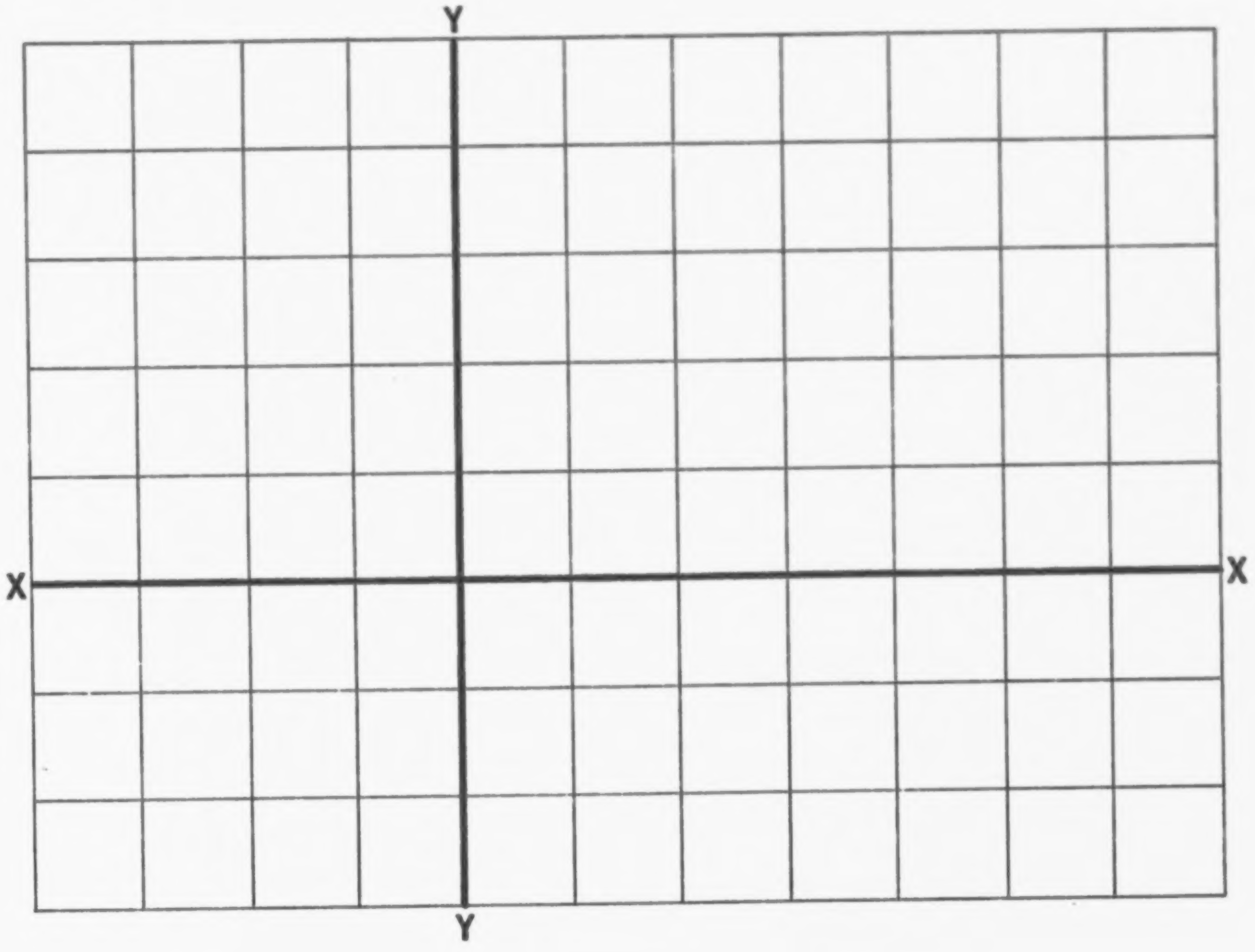
Appendix C

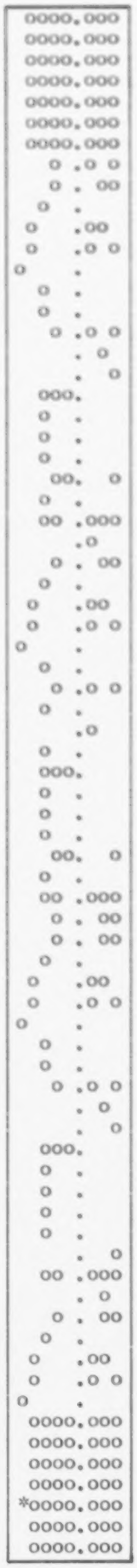
FINAL EXAMINATION

For questions 1 and 2 the following coordinates should be used, by plotting them in the grid below as they would occur on a two-axis drilling machine:

Absolute	Incremental	X	Y
(1)	(A)	1.000	1.000
(2)	(B)	2.500	1.000
(3)	(C)	3.000	-1.000
(4)	(D)	-3.000	2.000

1. Using the numbers (1), (2), (3), and (4), indicate the hole locations as they would result on a machine using the absolute system.
2. Using the letters (A), (B), (C), and (D), indicate the hole locations as they would result on a machine using the incremental system.





Final Examination (continued)

To the left is a section from the middle of a tape. From examination of the tape the following items can be completed.

3. The tape is in the __________ __________ format and uses a __________ sequential printout.

4. The minus signs must be punched in, but not the plus signs. True ______ False ______

5. Leading zeros need not be punched in, but all trailing must be punched in. True ______ False ______

6. All coordinate dimensions are _____ place decimals.

7. Only x and y coordinates are programmed. True ______ False ______

8. The positioning system is probably (absolute) (incremental). (cross out one)

9. What is the number of the first block of information? __________

10. What is the location of the first point shown? x __________ y __________

11. Write an ADAPT statement which would describe this point. ____________________

12. What is the number of the second block? __________

13. What is the location of this block? x __________ y __________

14. Write an ADAPT statement which would describe this point. ____________________

15. Write an ADAPT statement which would describe a line running through these two points. ____________________

16. In your opinion does this control contain a "memory"? Yes ______ No ______

17. What purposes do the rows of holes in the (*) area of the tape serve?
    a. ____________________
    b. ____________________

Final Examination (continued)

18. Fill in only the portion of manuscript below for which appropriate information is available from the tape and questions 3 through 17.

Misc. function	Sequence number	Tab or E.O.B.	±	x coord.	Tab or E.O.B.	±	y coord.	Tab or E.O.B.

19. Explain what is meant by a "parity check."

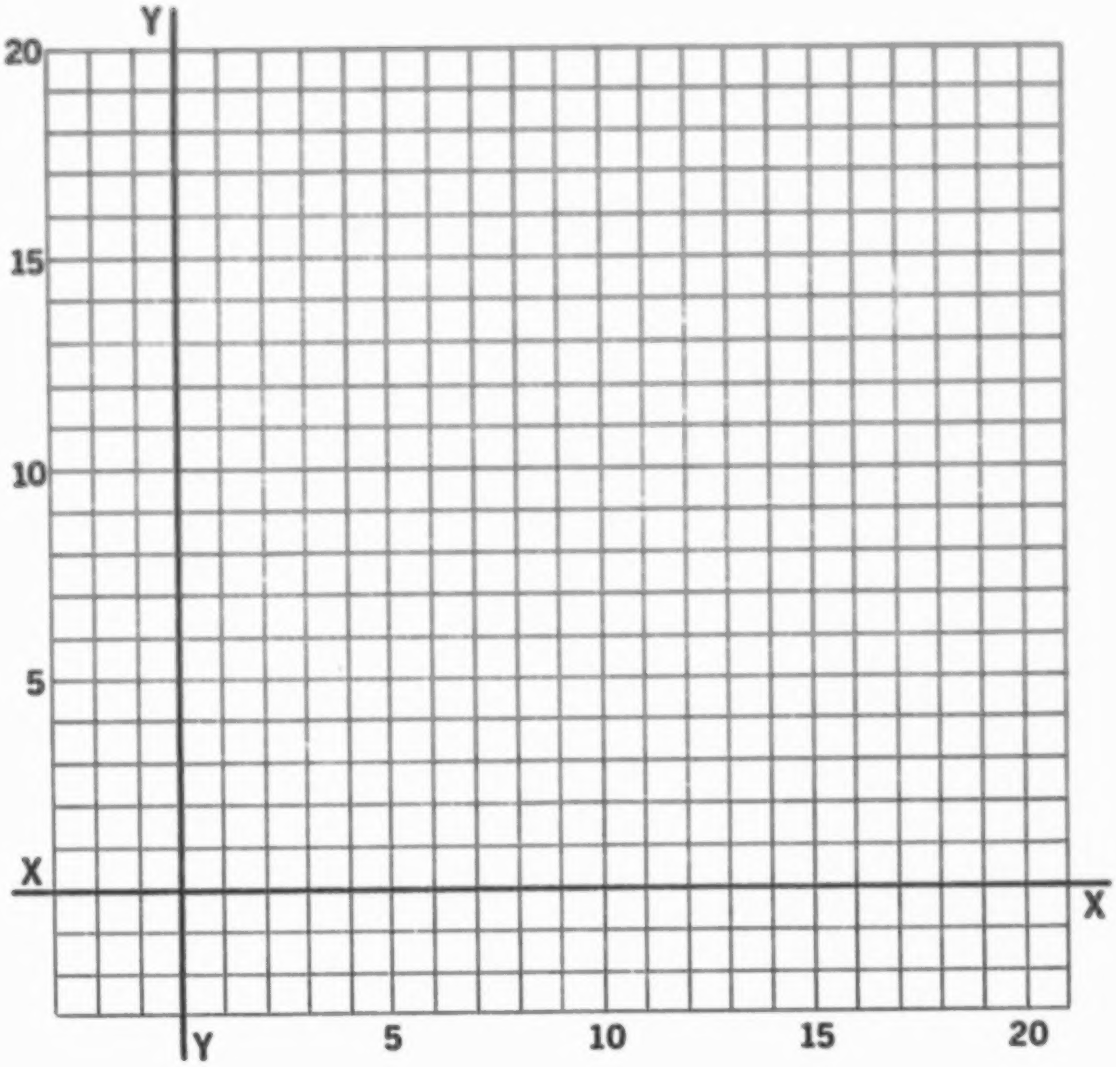
20. Explain what the terms MACRØ and LØØPING mean. What function do they perform? Which of these is available only with ADAPT?

21. Explain the differences between APT and ADAPT.

22. Name two other N/C languages, and classify each as to main function; that is, contouring or positioning.

23. The following is a simple ADAPT program. On the grid below, draw a sketch of the part that this program would produce.

```
PARTNØ      FINAL EXAM,
REMARK      TAKE YØUR TIME ØN THIS ØNE,
            MACHINE DREAMBØAT NØ. 1
            CUTTER/1.000
            FEDRAT/9
SETPT  =    PØINT / 1,1,0
            FRØM / SETPT
            INDIRP / 1,3,0
            GØ / (BASE = LINE / 1,3,4,3)
            TLRGT, GØRGT / BASE
            GØFWD / (CIRCLE / 6,5,2)
SLANT  =    LINE / (TIP = PØINT / 1,3) ATANGL, 45
            GØLFT / SLANT, PAST, BASE
            GØTØ / SETPT
            STØP, END
            FINI
```



24. A machinist is to use a 3" diameter cutter with 4 teeth to mill brass. The cutter is high-speed steel. A feed per tooth of 0.010" is desired to get the finish required.

    What is the most desirable speed? ____________

25. In the above situation, what rate would be set? ____________

26. The name for this rate is rpm. True __________ False __________

27. What is the indicated feed rate? ____________

28. What would be the desirable ipm? ____________

29. What is the probable horsepower requirement if the cut will be 2" wide and 1" deep? ____________________

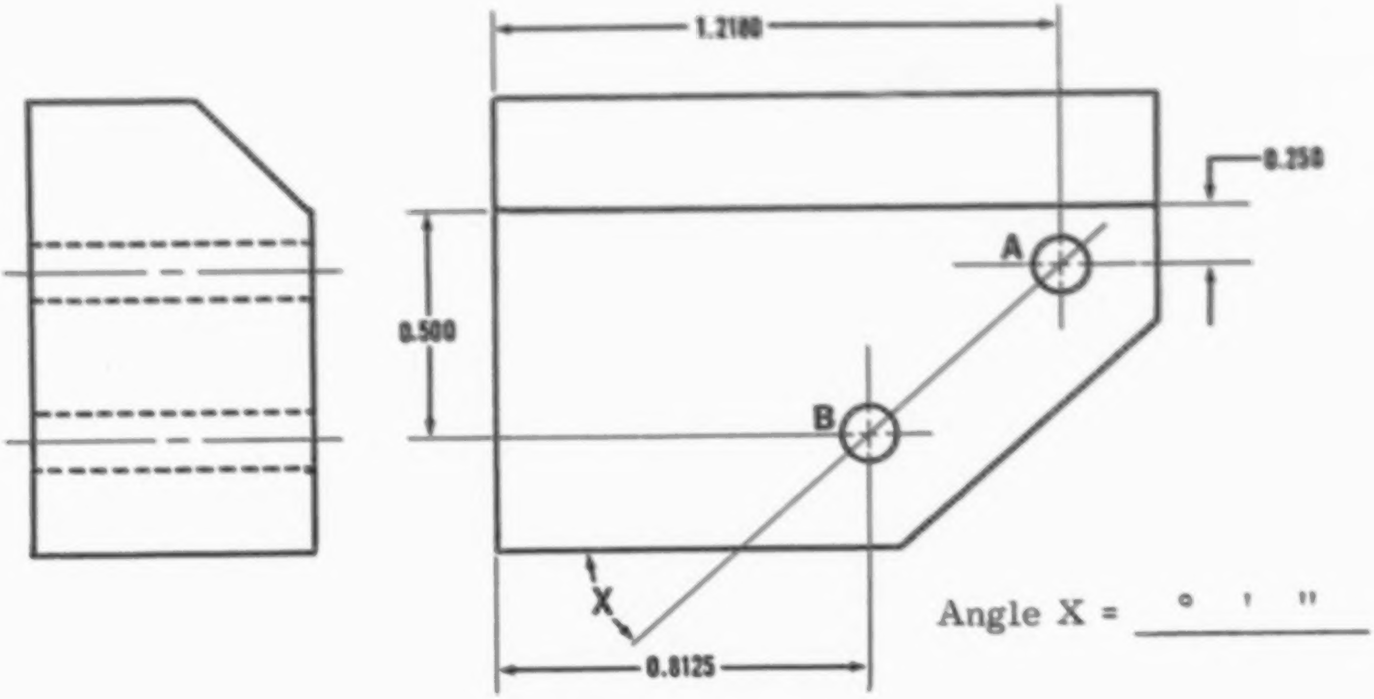
30. In the binary number system, the next number after 1001 is ____________.

31. 100 binary is ____________ decimal

32. 21 decimal is ____________ binary

33. Adding 1101 binary to 1001 binary gives ____________decimal.

34. At what angle will the program callout be written to cause the machine to drill the holes at A and at B.



Angle X = ____°____'____"

Appendix D

GLOSSARY

ABSOLUTE ACCURACY. Accuracy as measured from a specified reference zero.

ABSOLUTE DIMENSION. A dimension or numerical value with respect to an initial zero point of coordinate axes.

ACCURACY. (ASA C85) - Conformity of an indicated value to the true value, i.e., an actual or an accepted standard value. Note: Quantitatively, it should be expressed as an error or an uncertainty. The property is the joint effect of method, observer apparatus, and environment. Accuracy is impaired by mistakes, by systematic bias such as abnormal ambient temperature, or by random errors (imprecision). The accuracy of a control system is expressed as the system deviation (the difference between the ultimately controlled variable and its ideal value); usually in the steady state or at sampled instants.

ADDRESS. A label, name, or number identifying a location or a device.

ACTUATING SIGNAL. The difference at any time between the reference input and a signal related to the controlled variable.

ANALOG DATA. Data that are equivalent (or in an analogous form) to a required machine movement or position. This is in contrast to numerical data wherein the information is expressed as a number. The analog may be voltage, pulse, time, or length data, e.g., one pulse is equal to 1/1000 of an inch movement.

BINARY CODE. A code in which each allowable position has one of two possible states. A common symbolism for binary state is 0 and 1. The binary number system is one of the many binary codes.

BINARY - CODED - DECIMAL SYSTEM (BCD SYSTEM). A system of number representation in which each decimal digit is represented by a specific group and arrangement of binary digits such that only four levels are required.

BINARY NOTATION. The writing of numbers in the scale of two.

BIT. Bit is an abbreviation of "binary digit." It is a single character of a language employing exactly two distinct kinds of characters.

BLOCK. A group of words considered as a unit.

BLOCK ADDRESS FORMAT. A means of identifying words by use of an address that specifies the format and meaning of the words in a block.

BUILDING BLOCK AUTOMATION. See Detroit-type automation.

CHAD. The punches, pieces of material, which have been removed from tape or card.

CHADLESS TAPE. A punched tape wherein perforation is completed and no chad remains attached to the tape.

CODE. A system of signals or characters and rules for their interpretation. For punched tape, magnetic tape, or cards: a predetermined arrangement of possible locations of holes or magnetized areas and rules for interpreting the various possible patterns.

CONTROL POSITIONING ACCURACY, PRECISION, OR REPRODUCIBILITY. Accuracy, precision, or reproducibility obtainable on completed parts under normal operating conditions.

CYCLING. A periodic change of a complete course of operations that return to the original state or starting point of events.

DATA PROCESSING. The translation of numerically descriptive engineering and manufacturing data into a form suitable for machine control.

DEAD BAND. The range of values through which the input can be varied without initiating output response.

DEAD TIME. Any definite delay between two related actions. It is measured in units of time.

DECODING. Translating from a coded form without significant loss of information.

DETROIT-TYPE AUTOMATION. The in-line arrangement of conventional machining operations with special and general purpose equipment interconnected by material transfer devices and automatic sequencing of operations, continuously evaluated by automatic inspection and feedback of the deviations noted to central or operation control.

DIGITAL. Describing a discrete state of being such as the presence or absence of quantity.

DIMENSIONS (OVERALL). The full length of a movement or a programmed cut. May be plus or minus as related to a base dimension.

ENCODING. Translating to a coded form without significant loss of information.

END-OF-BLOCK SIGNAL (EOB). A symbol or indicator that defines the end of one block of data within the tape media.

ERROR COUNTER OR ERROR REGISTER. This is a device for accumulating and signaling the algebraic difference between desired machine movement and the actual movement of the machine.

ERROR SIGNAL. A signal inside a closed-loop system representing the difference between desired position and actual position.

FEEDBACK LOOP. The part of a closed loop system in which an output signal is provided to be used in comparison with the command signal.

MIXED SEQUENTIAL FORMAT. A format in which a word is identified by its location in the block. Words must be presented in a specific order, and all possible words preceding the last desired word must be present in the block.

FLIP FLOP. A circuit having two stable states, either of which may be induced by means of suitable input signals.

HOLD. An untimed delay in the program, terminated by an operator or by interlock action.

INCREMENT. The value which is added to a coordinate dimension to produce a change.

INSTRUCTION STORAGE. A device into which information can be introduced, held, and extracted later.

INTERLOCK BY-PASS. A command to temporarily circumvent a normally provided interlock.

MACHINE ACTUATOR OR MACHINE SERVOMOTOR. A power device for directly effecting machine motion.

MACHINE POSITIONING ACCURACY, PRECISION, OR REPRODUCIBILITY. Accuracy, precision, or reproducibility of the position of the machine elements and the machine-positioning servo. Cutter, spindle, and work deflection and cutter wear are not included. (May be the same as control positioning accuracy, precision, or reproducibility in some systems.)

MACHINE ACCURACY, PRECISION, OR REPRODUCIBILITY. Accuracy, precision, or reproducibility obtainable on completed parts under normal operating conditions.

MANUSCRIPT. A storage media, such as a planning chart, containing raw data in sequential form suitable for translation.

MEMORY. The portion of a system which can store or hold information.

MEASURING ACCURACY, PRECISION, OR REPRODUCIBILITY. Accuracy, precision, or reproducibility obtainable on completed parts under normal operating conditions.

MISCELLANEOUS FUNCTION. An on-off function of a machine such as spindle stop, coolant on, clamp, and the like.

NORMAL DIMENSIONS. Incremental dimensions of which the number of digits are specified in the Format Classification.

NUMERICAL CONTROL SYSTEM. A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret some portion of this data.

OPEN-LOOP SYSTEM. A system that has no means for comparing the output with the input for purpose of self-correction of error.

PARITY CHECK. A means of determining whether a character has an odd or an even set of marks to describe it. Usually characters in a code are all odd or all even. An extra "parity mark" is added to make this the case.

POSITION READOUT. A display of absolute position as derived from position feedback transducer.

POSITION SENSOR OR POSITION TRANSDUCER. A device for measuring a position and converting this measurement into a form convenient for transmission.

PROGRAMMING. Programming is the combining of numerically descriptive data with preplanned machine operation and sequence data to provide a series of coded machine commands.

PULSE. A pulse is a variation of a voltage or current consisting of an abrupt change from one level to another followed by an abrupt change to the original level.

RESOLUTION. The least interval between two adjacent discrete details.

ROUTINE. A set of coded instructions, supplied to a general-purpose computer, which establishes a sequence of operations to be followed in the logical processing of a class of data.

SEGMENT. The portion of a path joining two successive points.

SPECIFIED CUTTING TOLERANCES. Allowable deviations of measurement of a test part or parts from the programmed dimension, which may result from control error, machine deflection, backlash in slides, cutter run-out, cutter deflection, and the like.

SYNCHRO. Any member of a family of wound rotor magnetic induction transducers (known as selsyns, autosyns, and telesyns) that are capable of electrically transmitting and receiving angular position information.

SENSOR. A device which measures an output quantity and provides feedback information.

SERVOMECHANISMS. A family of systems that are error-actuated to eliminate the differences between actual and desired quantities, usually involving mechanical motion.

TRANSLATING. Changing information from one form to another.

TRAVEL. The distance moved between two points on a machine axis, usually given in inches.

VECTOR. A mathematical entity representing a directed magnitude.

VERIFY. To check, usually automatically, one typing or recording of data against another, in order to eliminate human and machine errors in the data transcription.

WINDUP. Lost motion in a mechanical system proportional to the force or torque applied.

ZERO POINT. A machine setup point (origin of motion) related to the linear and rotary axes, which can be a fixed reference or a movable (floating) reference.

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